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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOLUME VI.

BOSTON:
1893.

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1893, Sept. 11 - 1894, June 25.
Gift of the Editor.

THE Society of Arts, established in conformity with the plan of the Massachusetts Institute of Technology as set forth in the act of incorporation, held its first meeting on April 8, 1862.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement in connection with arts, agriculture, manufactures, and commerce. Regular meetings are held semi-monthly from October to May.

The Society has discontinued the publication of the *Abstracts of Proceedings*, and now publishes its proceedings and the principal papers read at its meetings in the *Technology Quarterly*. The present volume contains the proceedings from January, 1893, to December, 1893, inclusive.

The *Quarterly* contains, also, the results of scientific investigations carried on at the Institute, and other papers of interest to its graduates and friends.

Neither the Massachusetts Institute of Technology nor the Society of Arts assumes any responsibility for the opinions or statements in the papers.

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VOL. VI. APRIL, 1893. No. 1.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FIRST YEAR, 1892-93.

THURSDAY, January 12, 1893.

THE 440th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. Prof. G. R. Tucker and Mr. Frederick P. Royce, both of Boston, were duly elected Associate Members of the Society. The Executive Committee reported that they had filled the vacancy in their number caused by the regretted death of Mr. Charles E. Powers by the election of Mr. Henry C. Morse.

The President then introduced Prof. C. H. Peabody, of the Institute, who read a paper on "The Course in Naval Architecture at the Institute of Technology." The paper was illustrated with the lantern, and is published in full in the present number of the *Quarterly*. The meeting then adjourned.

THURSDAY, February 9, 1893.

The 441st meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. The following papers were read by title:

"Study of Bacteria in Drinking Water," by George W. Fuller, S.B.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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TECHNOLOGY QUARTERLY

AND

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VOLUME VI.

BOSTON:
1893.

tion in an irregular manner for nearly a century; it is only in comparatively recent years that a fixed policy has been followed. In 1811 a school in naval architecture was opened in Portsmouth, and again one was opened in 1853; neither was maintained long, and their influence was limited. In 1864 a school was opened at South Kensington, which in 1873 was united with the Royal Naval College at Greenwich. The men trained in the school at South Kensington now hold important positions either in government employment or in private yards.

The Royal Naval College is charged with all the higher scientific instruction for the British Navy, with the exception of gunnery and the use of torpedoes. The most thorough instruction is given to a small group of students, known as "students in naval architecture and engineering," extending through three years.

The English naval engineers are selected by open examination at fourteen to sixteen years of age, then pass a six years' apprenticeship in the dockyards and finish with a course of one year at the Naval College. Each year two engineers are selected to take two additional years' training at the college. In a similar manner dockyard apprentices, at the age of fourteen or fifteen, are taken into the dockyards for a seven years' apprenticeship. Every year three apprentices are selected by competitive examination for study at the Naval College. The examination for admission to the dockyards is much the same for both classes of apprentices, and includes arithmetic, geography, algebra, geometry, reading, and writing. Together with practical instruction the apprentices are taught in the dockyard schools algebra, descriptive geometry, analytical geometry, calculus, and mechanics.

The first year at the Naval College for both engineers and naval architects is much the same as for a rather large class of naval officers and naval engineers. Then a two years' course is given to the small and select class of engineers and naval architects, which is the same for both in theoretical work, but differs in professional work. Private students are admitted to the whole three years' course, and several of our later naval constructors have had the advantages offered by this school.

The theoretical work includes mathematics, physics, chemistry, and mechanics, and is of the highest character, including training in well-equipped laboratories. The special professional work in naval architecture is of particular interest, and will be given at length from an

account by Mr. W. H. White, then an instructor at the school and now the chief constructor for the English Navy. Though the account was given some years ago, it is substantially correct now. The course at that time was so complete that improvement would appear to be possible only in the perfection of methods and details.

In the first year one or two afternoons a week are given to ship calculations as follows:

1. Proofs and applications of rules for finding the areas and position of the center of gravity of plane curves.

2. Proofs and applications of the rules for finding displacement of ships and center of buoyancy.

3. Construction and use of curves of displacement, tons per inch of immersion, and area of midship section.

4. Proofs and applications of rules for calculation of the metacenters for transverse and longitudinal inclinations.

5. Construction and use of metacentric diagrams.

6. Explanations and applications of rules for tonnage measurements.

7. Graphic representations of the longitudinal distribution of the weight and buoyancy in ships floating in still water, together with the construction of the curves of loads, shearing forces, and bending moments.

In the earlier part of the second year the students are taught how to perform the following more difficult operations:

1. Calculations for statical stability and construction of curves of stability.

2. Calculations for dynamical stability by Moseley's formula.

3. Calculations for and construction of the loci of the center of buoyancy, metacenter, and center of flotation of ships for all tranverse inclinations under certain assumed conditions.

When this work is finished the students are ready for a ship design, which occupies two or three afternoons a week for the remainder of the second year and for the whole of the third year, and on this design the students work in twos or threes. The character and extent of the work is shown by the following outline:

1. Preliminary estimate of dimensions and displacement.

2. Preparation of sheer-plan, midship section, outline specification for scantlings, plans of decks, etc.

3. Calculations of displacement, and positions of the center of buoyancy and metacenter.

4. Detailed calculations for weight of hull, armored and fitted, together with the position of the center of gravity.

5. Detailed estimate of weights of equipment and position of their center of gravity.

6. Combinations of 4 and 5 to determine the weight and the position of the center of gravity of the completed ship; determination and application of corrections to the preliminary estimates, after which the design is made determinate and requires only the working out of details.

7. Preparation of outline profile and plans of decks and hold.

8. Preparation of sail draught, etc.

9. Calculations for and construction of curves of displacement, tons per inch of immersion, and immersed midship section; also for metacentric diagram.

10. Calculations for statical and dynamical stability.

11. Calculations for speed under steam.

12. Calculations for longitudinal bending moments in still water and among waves, etc.

13. Calculation of equivalent girder and estimate of longitudinal strains on the structure.

During the third year the students receive instruction by lectures and otherwise on the following subjects:

I. STABILITY OF SHIPS.

1. General theorems of Dupin, etc.

2. Metacentric methods of estimating initial stability, etc.

3. Applications of the metacentric methods, including: Inclining experiments to determine the vertical position of the center of gravity of a ship; variations of stability due to the addition or removal of weights; changes of trim produced by moving weights or the adding or removing of weights; efficiency of various methods of water-tight

subdivision in preserving the stability of ships when compartments are bilged; stability of ships aground; estimates of power to carry sail.

4. Stability at finite angles of inclination, with details of the various methods of calculation that have been proposed by Atwood, Read, and Barnes. Calculations for and construction of curves of stability. Examples of the forms of such curves for typical ships. Influence of beam, free board, draught, and vertical position of the center of gravity upon the forms of curves of stability.

II. DYNAMICAL STABILITY.

Moseley's formula and other expressions for dynamical stability; estimates by direct calculation or from curves of stability of the safety of ships when acted upon by gusts or squalls of wind; reserve of dynamical stability.

III. OSCILLATIONS OF SHIPS.

1. Unresisted rolling in still water.
2. Rolling in still water, with effect of resistance included.
3. Still water rolling experiments, etc.
4. Dipping oscillations in still water.
5. Rolling among waves.
6. Principal deductions from the theory of rolling.
7. Pitching oscillations.
8. Heaving and yawing.

With the paper by Mr. White are given diagrams showing work done by students, which differ only in detail from some that I shall show later in the statement of our own course.

Before giving a detailed account of our own course I ought to mention the very excellent course of naval architecture given at the University of Glasgow.

THE COURSE AT THE INSTITUTE OF TECHNOLOGY.

A brief history of the progress in instruction in marine engineering and naval architecture at the Institute of Technology will show that the growth has been natural, and that our course is well rooted and grounded. In 1886 options in mill, locomotive, and marine engineer-

ing were offered to the fourth-year students in mechanical engineering. To these options were assigned three lectures a week for one third of the first term and all of the second term. Though the time has remained the same, the options have been extended and strengthened by preparation and arrangement of material and by the improvement that has steadily gone on in the regular work of the third year. Inasmuch as it appeared advisable to give the students in marine engineering some idea of the form, construction, and properties of ships, an elementary course of such instruction was given in 1888: this was the first attempt to give regular instruction in this line in this country, for the excellent evening classes in ship-drawing in this city are intended for quite a different class of young men. Year by year the instruction has been improved and enlarged until some regular provision for it outside of the option in marine engineering became imperative. In 1890 the option of naval architecture was established, with two lectures a week for the second term of the fourth year. Last year a further expansion was made by assigning lectures and drawing exercises in the first term, and a substantial amount of work was done by students taking the option. This present year the instruction in naval architecture comprises three lectures a week the first term and two a week the second term, together with six hours of drawing each week for the entire year.[1]

In comparison with other schools we ought perhaps to give some account of the work in the course of mechanical engineering leading up to and accompanying the instruction in marine engineering and naval architecture, including the mathematics, drawing, chemistry, physics, applied mechanics, mechanism, steam engineering, modern languages, literature, history, etc., together with a description of the work and training in our workshops and in the laboratories of chemistry, physics, applied mechanics, hydraulics, and steam engineering; but such a statement would be tedious, and is unnecessary for those who are familiar with the methods and work of our school. The students taking the naval option are required to take the marine engineering option also, so that an account of this should be given. It includes:

1. Description of marine and stationary engines in all their details, including the most modern types.

[1] Since this paper was read, a regular four years' course in naval architecture has been established at the Institute of Technology, following the lines laid down here, but enlarged in scope and improved in details.

2. The usual discussions and calculations of the strength and proportions of marine and stationary engines.

3. Discussion of the probable behavior of steam in the cylinders of a proposed engine, considering different types and arrangements.

4. Discussion of the effect of the reciprocating parts in combination with the preceding work, with the object of determining the greatest stresses on the parts of the engine.

5. Comparison of these results with the results of the usual methods.

6. A discussion of the forms, efficiency, and construction of paddle wheels and propeller screws.

The last four involve a large amount of drawing and calculation by the students. The classroom work in naval architecture takes up the following subjects:

1. A description of the methods of building ships in iron and steel, including transverse and longitudinal framing, the fitting of double bottoms and ballast tanks, the laying out, erection and fairing of the framing, fitting of bulkheads, and the shell and deck plating.

2. Proofs and applications of rules for finding the area, moment, moment of inertia, center of gravity, and radius of gyration of lines, areas and volumes by Simpson's rule, the trapezoidal rule, and by the Amsler-Laffon integrator.

3. General discussion of the properties of floating bodies, with especial application to ships. Taking up the discussion of curves and surfaces of buoyancy and flotation, and of similar curves and surfaces for a layer due to increased displacement; the discussion of the metacenter and metacentric curves and of statical and dynamical stability. Also taking up applications of the metacentric method to inclining experiments for determination of the center of gravity of existing ships, to the determination of the variation of stability and the change of trim due to the addition, removal, or shifting of weights, and to the grounding of a ship, with especial reference to docking and launching. Also a discussion of the effect of carrying fluids in tanks wholly or partially filled, including water ballast tanks and double bottoms; also the effect of the flooding of the various compartments of a ship.

4. Explanation of the methods of finding statical and dynamical

stability of ships proposed by Barnes, Benjamin, Spence, Daymard, and others.

5. Explanation of the methods of finding the weight, center of gravity, moment, and moment of inertia of the hull, equipment, and cargo. Determination of loads, shearing forces, and bending moments acting on the hull of a ship in quiet water and when borne by waves.

6. Explanation of the methods of determining the equivalent girder for the hull of a ship and of determining the stresses produced by the weight of the hull, equipment, and cargo, whether floating in still water or borne by waves.

7. Rolling of ships.

8. The trochoidal theory of oscillating waves; waves of translation, their character and methods of formation.

9. Resistance of ships due to surface friction and to the formation of waves. Experiments on models and comparisons of ships of similar types.

10. Preliminary methods of laying out the design of a ship and procedure for completing the design.

A large part of the work detailed in the first seven heads has been given already, and the remainder is ready for the class. The work under the last head is not yet arranged, but some substantial work will be done. The drawing-room work includes:

1. The laying out and fairing of the lines of a ship. Figure 1 shows a set of lines drawn this year.

2. Calculation of a displacement sheet in the ordinary form.

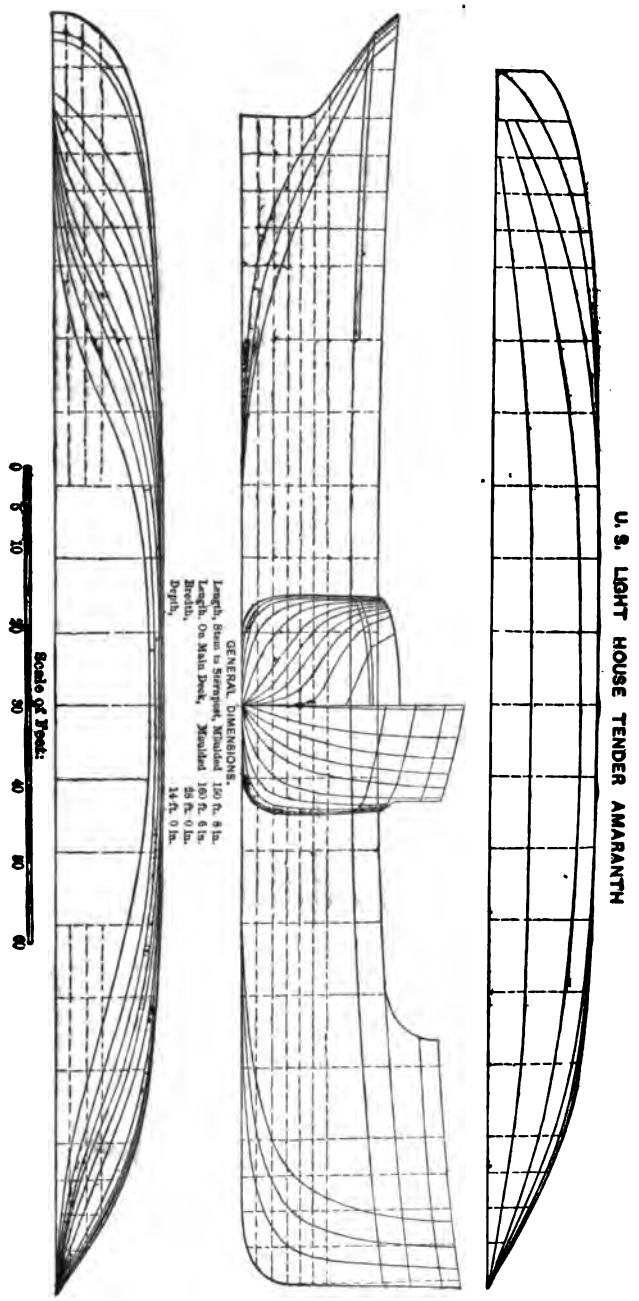
U. S. LIGHT HOUSE TENDER AMARANTH
GENERAL DIMENSIONS.
Length, Stem to Sternpost, Moulded 150 ft. 6 in.
Length, On Main Deck, Moulded 160 ft. 6 in.
Breath, 26 ft. 0 in.
Depth, 14 ft. 0 in.
Scale of Feet:
0 5 10 20 30 40 50 60

FIG. 1.

3. Drawing of curves of displacement, tons per inch of immersion, center of buoyancy, areas of midship section, areas of water lines, and transverse metacentric heights. Figure 2 shows such lines drawn this year.

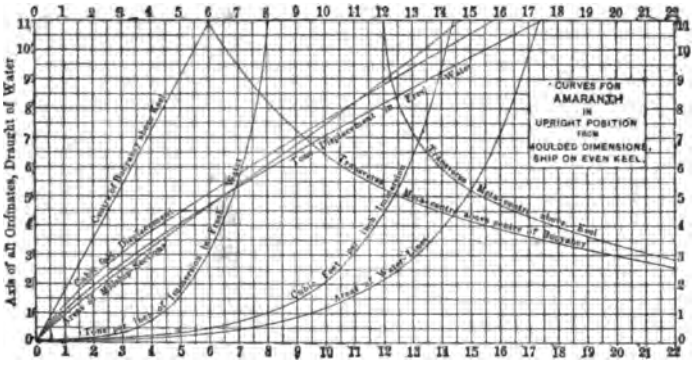
CURVES FOR AMARANTH IN UPRIGHT POSITION FROM MOULDED DIMENSIONS, SHIP ON EVEN KEEL.
Axis of all Ordinates, Draught of Water

FIG. 2.

4. Calculations of the statical and dynamical stability by the methods of Barnes and by the method in use at the Bureau of Construction and Repair of the Navy Department.

A double body plan used in the calculations by both methods is shown by Figure 3. The inclined water line used in Barnes' method

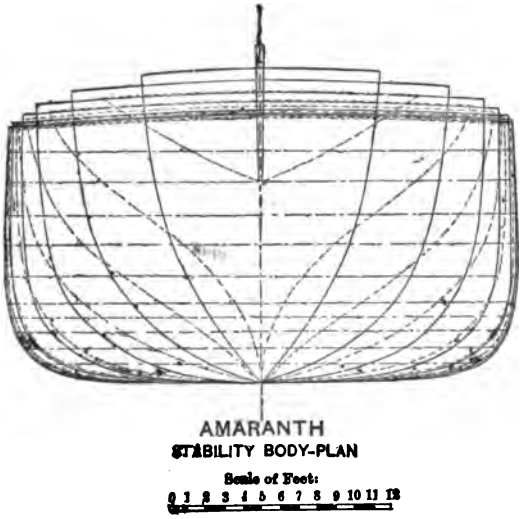

FIG. 3.

is shown by Figure 4. Figure 5 gives the cross curves used in the method of the Bureau of Construction and Repair, and the curves of statical and dynamical stability derived therefrom.

5. Calculations of the weight and center of gravity of the hull, equipment, and cargo; also the calculations for trim. For this work

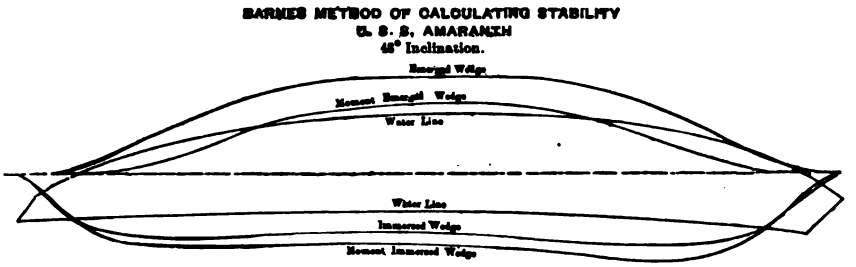

FIG. 4.

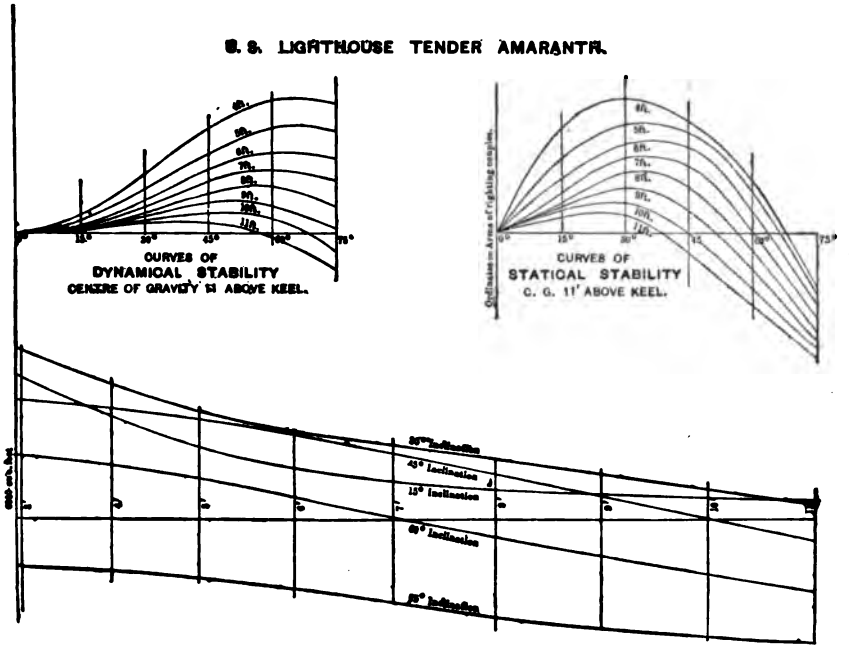

FIG. 5.

the student draws one of the sections of the ship, shown by Figure 6, and is furnished with other necessary data from the specifications of a ship recently built. Each student does enough of the work to

become familiar with the processes, and then the work of all the students is combined to complete the problem.

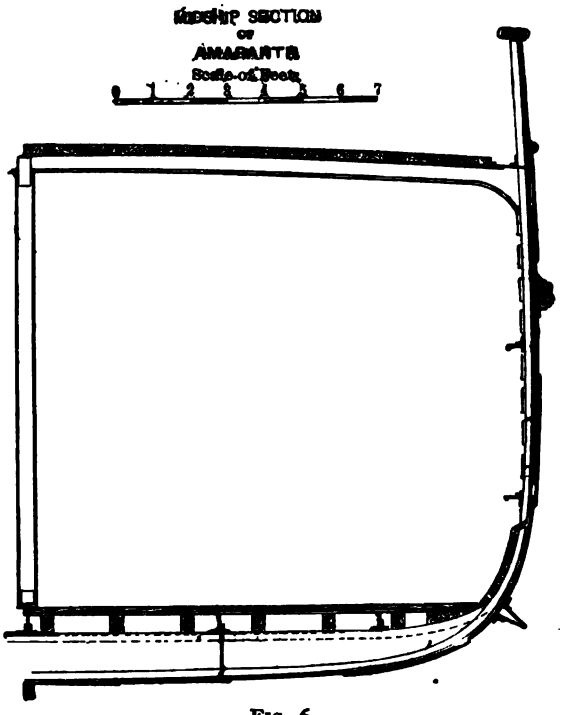

FIG. 6.

6. Calculation and drawing of the curve of buoyancy, weights, loads, shearing forces, and bending moments acting on the hull. The drawing is shown by Figure 7.

7. Drawing of the equivalent girder and calculation of the stresses on the hull.

The material that we have in the department, in addition to recent and standard works, includes drawings of many engines of important ships, both naval and mercantile, together with the lines and specifications of ships. Much of the material has been worked up in such a way that it is directly available for use with the class, and is now in use. Other material is promised to us as soon as ready, and will be worked up in a like manner.

Our course has been developed to conform to the needs and methods of our school, with the aid and advice of graduates of both the French

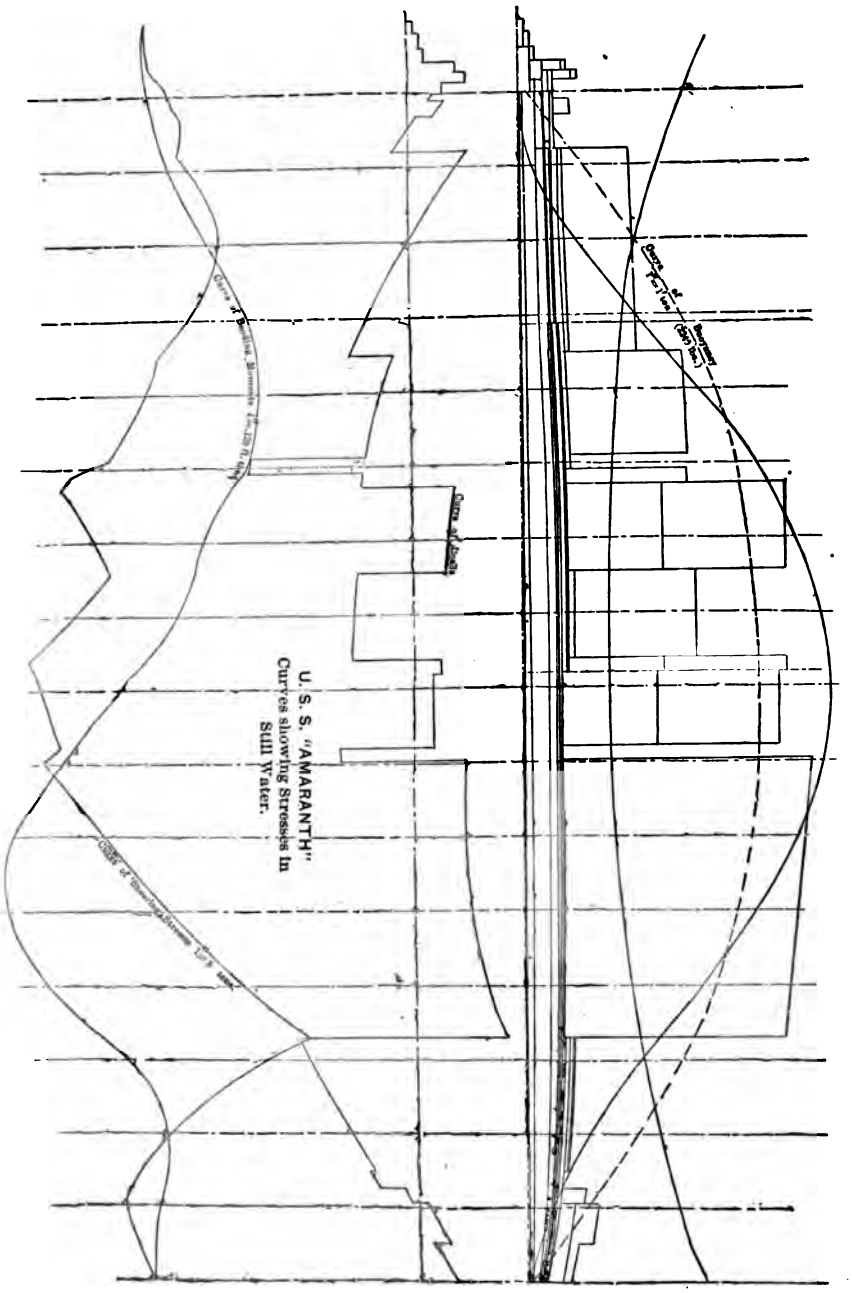

FIG. 7.

and the English schools, but without the intent of copying either. The instruction of our school differs from that of the English school in giving less time to drawing and calculation and in not attempting an elaborate design. In this work, as in all the work of the Institute, the time of the student is economized by careful preparation and arrangement of the work he is required to do, sometimes by lavish use of the time and strength of the instructing force. Each student is required to do enough of the detail work of calculation and drawing to familiarize him with the methods, and no more. In such work a large saving of time is made by a free use of mechanical integrators. In the course of drawing and calculation laid down, the student meets and masters all the problems that arise in the design of a ship, and applies them, as he learns them, to a ship of good design. Much of the work of a complete design of a ship is tedious and wearisome from the repetition of details. We do not believe that our men need or can afford to do much such work now. We aim rather to give a thorough grounding in principles, to teach good methods, and to give enough practice to enable the student to work intelligently. Finally, we believe that our graduates who take naval architecture will be able to begin work immediately in some useful position, even though it be at first a subordinate one; that they will quickly and thoroughly master that part of their profession which depends on experience; and that they will in time be able to take the highest positions the profession offers, in which they will only follow the traditions of our alumni.

MANUFACTURE OF HEAVY ORDNANCE WITH SPECIAL REFERENCE TO WIRE CONSTRUCTION.

By W. H. JAQUES, Ordnance Engineer.

Read February 9, 1893.

As a preparation for a comparison of the methods of employing "wire" with the generally accepted "built up" type, I will hastily review my lecture delivered January 6 before the Franklin Institute, Philadelphia, and illustrate the method of making our present form of heavy ordnance that you may be able to form your own estimates and make your own comparisons with what will follow in relation to "wire" construction. Both subjects are too extensive to have justice done them in a lecture of an hour and a half. I shall attempt, therefore, only a short historical sketch. For convenience in comparing the two methods I shall use the expressions "hooped" and "wire."

[Mr. Jaques then described the operations of manufacture, treatment, and assemblage of the "hooped" guns, giving an account of the material of which they are made and the growth of the mechanical means for its production; experiments with other materials and other types; development and test of nitro-compound powders; effective power of shrinkage; effects and prevention of erosion; methods of closing breech and checking gas; the value of nickel in steel; importance of "monster" guns; mortars, pneumatic and submarine guns; rapid-fire ordnance; effect of modern steel projectiles on steel, nickel-steel, and case-hardened (carbonized) armor; the whole illustrated by one hundred lantern views, a few of which, relating directly to "wire" construction, have been reproduced in this issue.]

Turning to that branch of gun-making, wire-wrapped ordnance, concerning which your Committee has asked me to speak, I find it even more difficult to formulate any *concise* statement that can help you to form an estimate of its value. A large amount of experimentation has been carried on, but few practical results have been obtained.

In England remarkable velocities and ranges have been secured, but these have been equaled by the "hooped" gun; in Russia the guns tested have shown great endurance, but in other countries nothing of importance has been done. In the United States, of the two guns tried one failed, while of the other (cast iron) the Board of Ordnance and Fortification has reported: "The muzzle energy of the gun is so much less than that of the steel gun, and the erosion so much greater, that the Board for Testing Rifled Cannon does not recommend it as suitable for service under present conditions." It must be remembered that the tube of this gun is of cast iron, and that its rejection must not be ascribed alone to its belonging to the class of "wire" guns.

This type of construction, in one form or another, appears to ante-

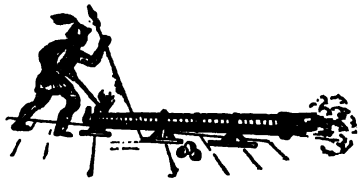

FIG. 1.

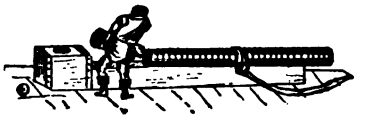

FIG. 2.

date all others. In seeking for the earliest date when ring, hoop, or coiled guns were used, in order to mark the stages of transition, I have not been able to find anything earlier than the statement of Archdeacon Barbour that Edward III, with whom he was contemporary, employed cannon in 1327 in his campaign against the Scots.

Froissart refers to the general employment of cannon in 1340, but does not give until 1390 his first representation of the guns of the period (Figure 1). The next illustration of an iron gun is that of the battery of the "Mary Rose," a war vessel sunk in 1545. The gun, of which Figure 2 is an approximate sketch, is said to have been recovered after an immersion of three hundred years. Both guns are evidently breech-loaders, and each is formed of a tube probably with a longitudinal lap (perhaps welded), additional transverse strength being obtained by shrinking on the narrow rings shown in the sketches. These rings were supposed to be made from iron three inches square, and the earlier descriptions call them "immense rings." These "immense rings" have dwindled to 0.03″ section for wire, and developed

(as the means of producing them have been provided) into jackets, for the 13-inch navy gun, for example, of $38\frac{1}{4}$ inches outside, and $23\frac{3}{4}$ inches inside diameter by $204\frac{1}{2}$ inches in length, weighing eighteen tons. The hoops or rings referred to above were driven over the tube or barrel when hot, the usefulness of shrinkage, although not carried to thousandths of an inch, being then recognized.

Both wire wrapping and wrought-iron coils are doubtless further developments of the barrel-welding of small arms. Greener says: "In the routine of good gunmaking, barrel-welding in importance is inferior only to the *quality of iron*," and that "the best barrels have more joinings than common ones of equal length." This would seem to be true of the modern wire-wrapped gun, since the greatest elastic strength is obtained with the smallest section.

Although with the ultimate object of producing tubes and hoops, the next prominent method of wrapping metal was that employed in the construction of the guns to which the names of Armstrong and Fraser were given. The coiled-iron cylinders of Armstrong, which have received so much adverse criticism, may be taken as a species of wire-gun construction, a type in which the cross-section was excessive. The spiral winding and lateral welding gave slight longitudinal strength; but the material — iron — was not strong enough, and the guns were always unreliable. In referring to the system in 1882, Armstrong argued in favor of these coiled cylinders because the barrels of fowling pieces had long been made on the principle of welding a spiral coil of soft iron in a continuous tube, and he believed that coil cylinders of the continuous fiber of rolled iron would resist the more potent bursting strain, while the lateral welds would provide sufficient longitudinal strength. In practice, however, this proved not to be the case. This method of construction, although retained in Great Britain from 1857 to 1885 (probably the longest period held by any British type), was not adequate, and many guns built in accordance with it came to grief.

To get longitudinal strength in his gun of 1860, Armstrong used an intermediate layer between the outer and inner coils, composed of iron slabs bent into cylindrical form and welded at the edges. The reason for this construction was that the intermediate layer has chiefly to sustain the thrust on the breech, and it is therefore desirable that the fiber of the iron should be in the direction of the length, while elsewhere in the gun it is more advantageously applied in the trans-

verse direction. Armstrong here provided separate means for resisting the longitudinal and transverse strains, but did not separate them as Longridge does in his type. It is a point that might well be considered whether the increased friction resistance of the "shrinkage" form is not of more value than any tendency of separation that this friction might produce. In 1863 the coiled wrought-iron tube was replaced by a steel forging, but the wrought coiled strengthening hoops were retained.

The bars for these coils were all about 3″ x 5″ section, 30′ lengths being end welded and wound upon a mandrel. The coiled cylinders (Figures 4 and 10) thus made were placed upon end, welded, and shaped under a hammer until cylindrical hoops (Figure 7) of the requisite length were formed. These lengths depended somewhat upon the capacity of coiling and welding machinery, but usually had to be made in short lengths because of the unequal welding of a large number of joints.

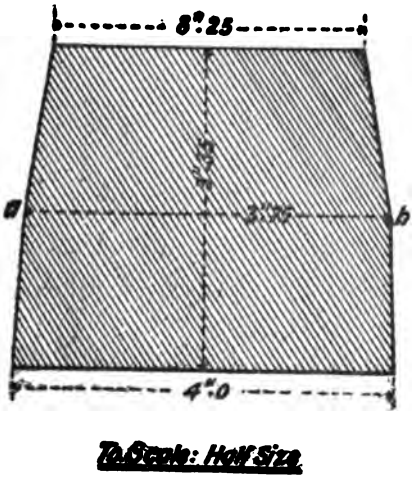

FIG. 3.

FIG. 4.

In 1867 Mr. Frazer, attached to the Woolwich establishment, simplified the Armstrong construction by reducing the number of coils, making them of thicker bars, and welding the trunnion band upon the breech coil; and in 1874 it was probably brought to its highest stage of efficiency when the 12-inch, 38-ton, muzzle-loading rifle composed of steel tube and wrought-iron coils gave a muzzle velocity of 1,410 feet seconds and a muzzle energy of 9,650 feet tons to a 700-pound projectile of 3 calibers length. In this gun the tube coils were welded from 4″ x 7″ section wrought iron, and the strengthening coils from 7″ x 12½″ section.

In Great Britain the change from wrought-iron coil ordnance to

forged steel, when it did come, was rapid. An English authority writes: "In 1882, when a powerful British fleet engaged the forts of Alexandria, there was no heavy gun on board in the construction of which wrought iron had not been largely used; nor were there any heavy breech-loading guns; while to-day (1891), on the contrary, all our modern iron clads are armed with breech-loading guns built entirely of steel."

FIG. 5.

FIG. 6.

The departure in both directions from Armstrong's wrought-iron coil construction resulted in an increase of strength. By way of the "Frazer" modifications the solid steel hoops and jackets were reached, while by way of thinner and smaller coils the wire system was perfected, in both cases steel becoming the accepted metal.

Although Armstrong's name has been welded to the coil construction, Blakely, I believe, had secured a patent for it before Woolwich and Elswick adopted it. The British patent records credit him with the idea.

The failures of the coiled iron guns showed them to be very deficient in longitudinal strength, the splitting of the inner coil and the separation of the coils being of frequent occurrence. Even with the low pressures employed, the wrought-iron coils were stretched beyond their elastic limit, and the barrel, not being adequately supported, gave way.

FIG. 7.

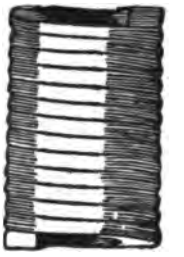

FIG. 10.

In the United States wrought-iron coils were extensively used for the conversion of Rodman and Dahlgren guns into muzzle-loading rifles. In the fabrication of the coil wrought-iron gun tubes, at the West Point Foundry, for the conversion of 10-inch Rodman smooth bore guns into 8-inch rifles, Lake Champlain pig was puddled and rolled into 23′ bars of 3.25″ to 4.0″ x 3.35″ irregular cross-section (Figure 3); these were scarfed to requisite coiling lengths by butt and lap welding, after which they were heated in long furnaces and coiled (Figure 4) upon a taper mandrel operated by steam. The coils were then welded (Figures 5 and 6) in banded cast-iron tubes called "welding pots;" after which the sections (Figure 7) were end welded to form the tube. In the Armstrong

wrought-iron coils the cross-sections of the bars employed were 2.2″ to 2.5″ x 3.2″ for the 8-inch (Figure 8) and 3.05″ to 4″ x 5″ for the 12-inch tubes (Figure 9), both of irregular cross-section. The coiling was done by Armstrong and at West Point by similar methods.

For forty years the names of Longridge, Woodbridge, and Shultz, and later Armstrong, have been prominently identified with "wire" gun experiments and development. To many others who have entered the race, reference will be made hereafter. Dr. Woodbridge's claim of priority of the idea seems to be established by the record of a plan for a wire-wound gun presented to the War Department July 30, 1850. Although Blakely's name has not been frequently mentioned, a patent for the use of coils

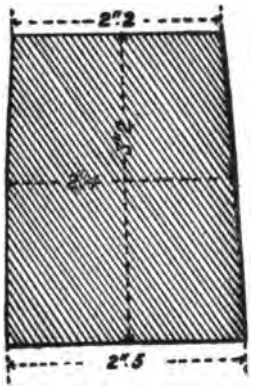

FIG. 8.

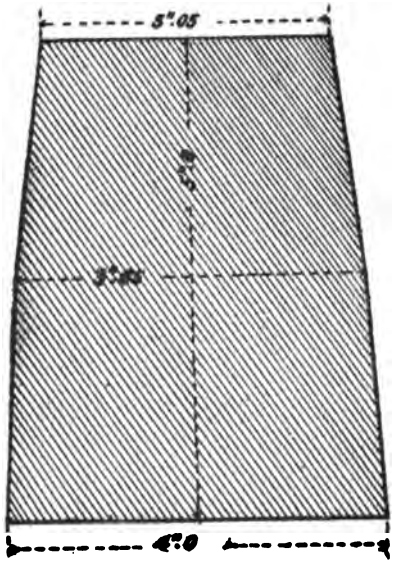

FIG. 9.

of wire for the strengthening of old and new guns was granted him February 27, 1853.

The early objects of wire construction were not only to increase the strength of guns, but to lessen the weight of the parts used in the construction of "heavy ordnance" before the advent of the mechanical means and metallurgical experience that have brought about the successful production of gun steel to so well meet the requisites of high power construction. Steel wire of small section and different forms was employed. The great increase of the elastic strength of steel by wire drawing enabled the requisite tangential cohesion to be

easily secured, but the condition was complicated by an absence of adequate longitudinal or end strength. From a good wire steel of 75,000 pounds tensile and 37,000 elastic, physical qualities of 250,000 tensile and 200,000 elastic limit have been obtained in a square section of .07″, and in No. 22 music gauge steel wire the strength has run as high as 142 tons per square inch. While this high elastic strength is of great value in caring for transverse strains, it has not yet been successfully applied to decrease to any great degree the lack of longitudinal or end strength, which is an inherent defect of most wire-wrapped types. Longitudinal winding has been tried, but it increases the difficulty of manufacture; and the excrescences upon the tube or body of the gun often prevent uniformity in the metal, while the sudden changes of form interrupt the synchronous and elastic movement of the metal and produce rupture.

From the prolific literature on the subject I have selected the opinions of some of the men who have given the question careful thought and who have directed many of the experiments, and I have at least kept the system among its friends.

In respect to the use of steel wire of comparatively small cross section or of steel ribbon, Armstrong claims, although his patent is dated December 28, 1880, to have given it his practical attention as early as 1855, and referred to it at considerable length in a lecture delivered before the British Institute of Civil Engineers January 10, 1882. He spoke of the system as being still in an experimental state, but believed it would attain wide application although there seemed many difficulties of putting the theories so strongly advocated into practice.

Armstrong also stated that in 1856 Mr. Brunel independently conceived the same idea as that presented by Blakely and Longridge, and requested him (Armstrong) to make a gun on the wire-wound principle; but that soon becoming acquainted with the priority of other patents the idea was given up by both Mr. Brunel and himself. In 1878 Armstrong's attention was again directed to the subject, when the patents already referred to having expired he made some preliminary experiments with small cylinders and in 1879 commenced the construction of a 6-inch breech-loading gun, which was completed and tested the following year. With it larger charges were used and higher energies obtained than with similar calibers of other types. As these results were satisfactory, a 26 cm. (10.23 inch) was constructed. It was

29 calibers long and weighed 21 tons (Figure 13). His 6-inch gun depended for longitudinal strength upon the cohesion of the barrel only, but in the latter (10.23 inch) he employed longitudinal layers of wire in the proportion of one longitudinal to four transverse layers. Of this particular construction Armstrong has written: "The longitudinals are secured to the trunnion ring at one end and to a breech ring at the other, and are in themselves calculated as sufficient to resist the end strain on the breech independently of the strength afforded by the tube. The whole is encased in hoops shrunk upon the exterior of the coil, for the treble purpose of protection from injury, of preventing slipping in the event of the failure of an external strand, and of adding to the strength of the gun. With regard to the ribbon form of section, I prefer it to a square section of equal area as being more favorable for bending over a cylinder; but any rectangular form is better than round wire on account of the flat bedding surfaces it affords." This gun when tested gave results unexampled, in relation to its weight, except by its 6-inch predecessor.

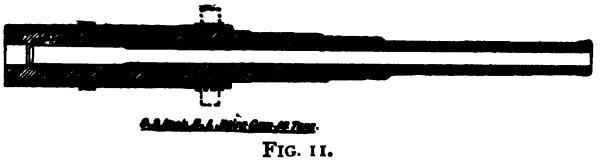

FIG. 11.

In 1884 Colonel Maitland referred again publicly to constructions

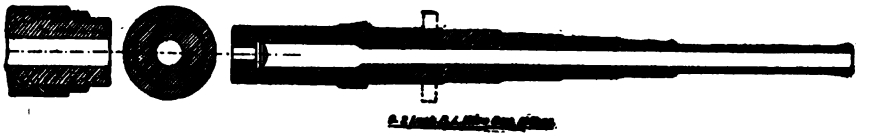

FIG. 12.

"which involve the employment of wire, which may, perhaps, supersede those consisting entirely of forged steel. They are chiefly experimental, but some have been made and actually issued for service to Chili by the firm of Sir W. G. Armstrong, Mitchell & Company. Competitive designs have been prepared for the War Office by the same great firm and by the Royal Gun Factory for guns of this kind. Figure 11 shows a section of the 18-ton wire gun proposed by Elswick. The Royal Gun Factory design submitted at the same time is shown

in Figure 12. In this latter construction the whole of the metal over the chamber assists in supporting the transverse strain. The longitudinal strength is divided about equally between the tube and the outer hoops, and is ample."

This desire to diminish the weight of ordnance is not limited to any recent period. Several times in the history of gunmaking lightness of construction has been carried to excess with consequent reactions. Colonel Chesnsey and Captain Fave describe a method of construction to secure lightness in which different materials were employed from those now used for wire-wrapped ordnance; and if there had been a patent union in existence in which Gustavus Adolphus could have secured a patent for the principle he might have reaped quite a valuable sum for royalties. These guns were made partly of boiled leather, and were used by Gustavus Adolphus at the battle of Leipsic, in 1631. They consisted of a thin cylinder of beaten copper screwed into a brass breech, the chamber of which was strengthened by four iron bands. The tube was covered with layers of mastic, over the entire length of which cords were firmly wound, and equalized by a layer of plaster. A coating of leather, boiled and varnished, completed the piece.

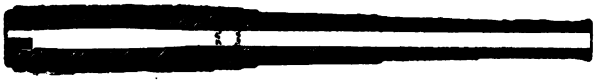

FIG. 13.

In this description we find nearly all the elements of a principle of wire gun construction except the separation of the provisions for longitudinal and transverse strength. The gun was chambered, the chamber was jacketed, coils of rope provided tangential strength, while the leather covering protected the coils from injury.

In various papers read before the British scientific institutions the advantages of "wire" construction have been presented and frequently discussed by Armstrong, Maitland, Longridge, Bramwell, Jones, and Hope. Many other authorities have spoken favorably of wire-wrapped ordnance, but since the appointment of Dr. William Anderson as Director General of Ordnance Factories the manufacture of wire-wound guns has rapidly progressed at Woolwich. Dr. Anderson has been interested in wire-gun construction for many years, and has always advocated the Longridge system.

The condition of the question in England in 1891 was well described in the issue of the London *Engineer* of October 2, 1891: "The

points which in our judgment deserve attention specially in connection with the gun factories at present are the manufacture of wire guns and the behavior of steel under the action of the burning of the powder charge. Mr. Longridge may at all events at length have the gratification of seeing wire guns likely to come in on a sweeping scale. For several years past their superiority has been fully recognized."

In 1892 Dr. Anderson himself expressed the opinion that a large gun made of steel wire must necessarily be more reliable than a gun built up of forgings. He gave as his reason for this "that we know

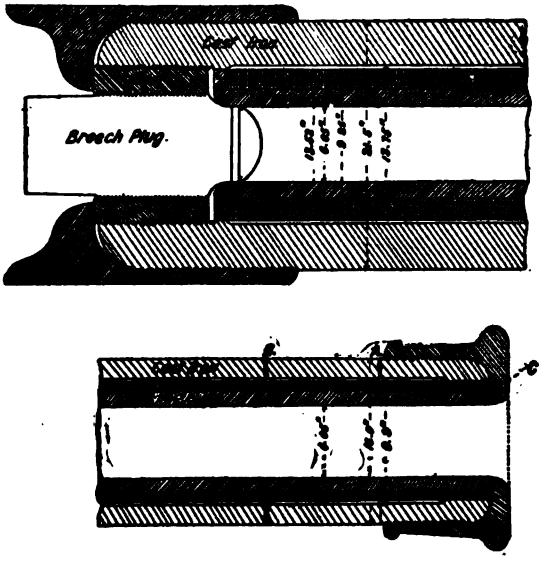

FIG. 14.

nothing of the internal molecular conditions of large masses of steel, whereas we know the exact state of structure built up of separate wires. Then, also, the tensile strength of steel wire is more than twice as great as that of a mass of steel." Dr. Anderson stated that they are conducting experiments with wire guns at Woolwich Arsenal, and that in all probability he will be able to give the results shortly.

Mr. Longridge has been the most persistent advocate of the application of wire to the construction of ordnance, and among the several forms that have emanated from the many inventors his last is undoubtedly the best type. His suggestions for the complete separation of the longitudinal and transverse strength are valuable, and the use

of the long jacket not only provides ample longitudinal strength, but serves to protect the wire from injury and displacement.

March 18, 1887, the British Parliament asked some questions "about a Longridge wire gun, said to have been made at Aboukoff, which had fired 1,500 rounds, and which was reported to have been made in half the time and at two thirds the price of those now in the British service." The result was that the British Admiralty recommended that trials with wire guns should be pushed on, Mr. Longridge having confirmed the Russian statement that such guns could be made in half the time and at half the price of the British guns.

April 26, 1888, a 6-inch Longridge wire gun, which was being tested at the proof butts on Woolwich marshes, burst, blowing away a portion of the muzzle. The construction of this gun with the ruptures at A and B is shown in Figure 14.

In May, 1888, Mr. Longridge wrote me of this accident to his 6-inch breech-loading gun. : "Its projectile of 99 pounds was fired with a 34-pound charge of pebble powder. The projectile moved quite freely in the grooves after it was once entered, and nothing in the way of wedging or jamming took place. The velocity was about 1,850 feet seconds, and the pressure gauge showed a pressure of about 25 tons per square inch. The muzzle ring and about eight inches in length of the cast-iron jacket were blown away to the butt, carrying away a gun-metal hoop that had been shrunk on to the end of the coil, uncoiling a small portion of the wire without breaking it. There was another fracture of the jacket about a foot to the rear of the muzzle ring, but this portion was only moved forward about one half inch in the coil. As the tube and coil were perfectly free to move forward in the jacket, except in so far as they abutted against the flange of the steel muzzle ring, it is clear that the whole of the strain which ruptured the gun must have arisen from the tube and coil moving forward, which in fact they did to the extent of about one inch. The causes of this movement were:

"The powder pressure acting upon the difference of area of the obturator and the section of the bore through the grooves.

"The friction of the projectile due to the reaction required to give rotation. The force required to bring back the tube and coil with the jacket in recoil.

"The friction of the products of combustion against the surface of the bore.

"The amount of this last, in the absence of direct experiments, is very difficult to estimate. I feel convinced that the accident to the gun at Woolwich was due to my underestimate of the effect of the friction of the products of combustion, and to a consequent error in the design of the gun."

Toward the end of 1891 Mr. Longridge sent me a copy of his letter to the London *Engineer*, in which he said: "It is in Russia only that my system has had a fair trial, and this is due to the energy and perseverance of Admiral Kolokoltzoff, chief of the Aboukoff works. You express a wish for definite data up to the present time respecting the first wire gun made in Russia. The gun was a 6-inch gun, breech-loading, with interrupted screw and De Bange obturator; length over all, 17 feet, 6 inches; weight, $5\frac{1}{2}$ tons; made at Aboukoff in 1888. After firing 1,000 rounds, with charges of $39\frac{1}{2}$ pounds and projectiles of

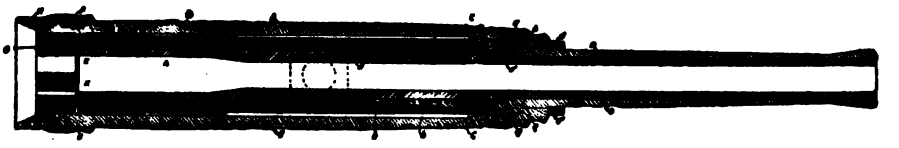

FIG. 15.

122 pounds, the gun was taken to pieces and a new A tube taken, to which the same wire coil, jacket, breech apparatus, and so forth were applied. The gun was then fired 500 rounds, and the authorities being perfectly satisfied, the firing was not carried further. The operation of taking to pieces and rebuilding the gun was very quickly and easily performed, and the cost was practically that of the new A tube only, about one fourth part of the weight of the gun. Since then they have made eight more 6-inch wire guns at Aboukoff, all of which have been perfectly successful, and thirty-two more have since been ordered by the Russian government. Guns of larger caliber are also under consideration, and in a recent letter from Admiral Kolokoltzoff, he speaks very confidently of their adoption ere long. I may perhaps also mention that experience has already proved the great economy of cost of the wire system over the forged steel guns and their much greater rapidity of construction. At last wire guns are recognized even at Woolwich. They are now making sixty of such guns. They are using my formula and are adopting my principle of separating the lon-

gitudinal from the bursting strain (Figures 15 and 16); they are, in fact, practically making use of the principles which I have been advocating for nearly thirty-five years and which have proved to be correct."

Mr. Longridge claims that the government will save from 30 per cent. to 33 per cent. in first cost, besides having much stronger and safer guns. The section of wire to be used is rectangular, $\frac{1}{4}$ inch by $\frac{1}{16}$ inch. Its ultimate tenacity is 100 tons and its limit of elasticity 65 tons per square inch. The Longridge patents are, I believe, now owned by Messrs. Easton and Anderson, of London.

Germany has recently built a few wire guns that are reported to have given favorable results.

In France considerable attention has been given to the subject, and a number of guns have been manufactured; but the failure of the

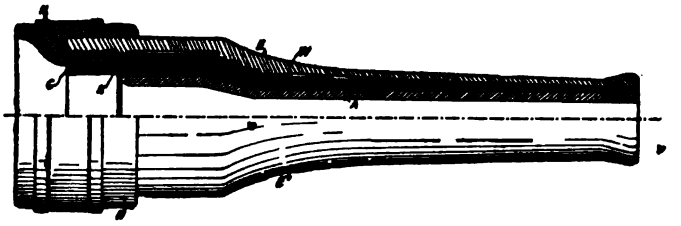

FIG. 16.

34 cm. (13.4″) gun made at Fives-Lille in 1882 and the successful production of "hooped" guns have combined to stop any active development in the direction of "wire" methods.

Although large sums of money have been appropriated for this purpose, the Departments of the United States have not prosecuted this branch of gun construction with much activity. In 1882 General Benet called the attention of Congress to the serious consideration which artillerists in France and England were giving to the system of construction covering the use of steel wire or ribbon, and several boards subsequently recommended the manufacture and test of several guns of this system. Dr. Woodbridge having been given the credit of priority of invention, and being an American, his plans were adopted and followed until very recently, when two new types, the Crozier, called the Department gun, and the Brown Segmental Tube Wire gun, were recommended for test. The consequence is that one Woodbridge gun was tried and failed, another has been condemned as being of too low

power, and three others await trial and completion. One of these is a 5-inch Navy breech-loading rifle, awaiting brazing and test. These together with the Crozier and Brown constitute our experimentation in wire-wrapped ordnance. Other systems and types have been suggested, but difficulties of various kinds have prevented their completion.

The Board of Ordnance and Fortification, in its report for 1892, states that the Crozier wire-wound 10-inch breech-loading rifle, also known as the Ordnance wire-wound gun, being made from designs of the Ordnance Department, is approaching completion at the Army Gun Factory at Watervliet. This gun, as stated in the former report, consists of a steel tube, overlaid from breech to muzzle with a practically continuous covering of steel wire wound in layers, with a jacket cylinder enveloping the steel wire over the reinforce and a continuous layer of steel hoops covering the wire from the trunnion band forward to the muzzle. The coils of wire are electrically welded end to end, so that the gun is wound with a continuous strand of wire. The breech mechanism is of the usual service type. This high-power gun will be completed, and will doubtless be tested, during the coming year.

Captain Crozier advocates the use of castings for the jackets, but in this particular gun I believe the jacket is a forging. The general idea of the type is to have the wire as little interrupted as possible by hoops, etc., between the breech and the muzzle; to have the jacket take the longitudinal strain; and to so arrange the general construction that no part except the tube need be of expensive material, without any sacrifice of strength thereby.

As already stated, Dr. Woodbridge presented plans for the employment of wire in the construction of a gun as early as 1850, but the patent granted him in 1882 describes his present type in which "a cylinder composed of longitudinal bars or staves" is provided as "the chief resistance to longitudinal strains." Describing the wire he says: "It should be either square or flat with a rectangular cross-section; should be 'tinned' or coated with a metal of low fusibility capable of being used as a solder. This serves as a preparation for soldering, or as a protection against oxidizing and to increase the resistance to slipping of wire upon wire." The wire drawn by the John A. Roebling's Sons Company for the Woodbridge guns was $\frac{1}{10}$ inch square section (about No. 12 of their wire gauge) and gave an average tensile strength of about 170,000 pounds. The wire was tinned for brazing.

The Board on Heavy Ordnance and Projectiles reported in 1882 that: "A gun of 10-inch caliber, after the design of Dr. W. E. Woodbridge, was recommended for construction by the Board on Heavy Rifled Ordnance. This device involved a steel tube to be bound around by steel wire under the requisite tension, and to be united by brazing with bronze. The gun was constructed at Frankford Arsenal and submitted to a trial of 93 rounds, 83 of which were fired under the direction of this board. It burst into two parts (under longitudinal strain) just behind the trunnions, under a powder pressure of about 80,000 pounds to the square inch as measured by the Rodman gauge." The projectile weighed 390 pounds; powder charge, 75 pounds.

A 10-inch breech-loading rifle, cast-iron wrapped, was completed at the Watervliet Arsenal in 1891. This gun has a length of bore of 28 calibers, and weighs about 28 tons.

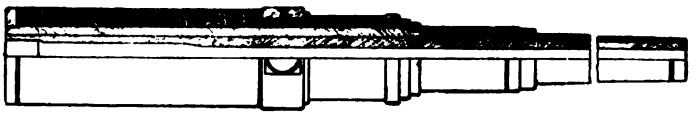

FIG. 17.

The Board of Ordnance and Fortification reported in 1892 that the gun has been fired 161 rounds and the test regarded as completed. It has thus far stood the tests to which it has been subjected, yielding velocities of 1,840 feet per second with a charge of 160 pounds of powder and a projectile of 453 pounds; they consider that the muzzle energy of the gun is so much less than that of the steel gun and the erosion so much greater that the Board for Testing Rifled Cannon does not recommend it as suitable for service under present conditions.

The 10-inch wire-wrapped breech-loading steel rifle built under the supervision of Dr. Woodbridge is practically completed. It (Figure 17) consists of a continuous steel tube, overlaid throughout its rear half with a cylinder of closely fitted steel staves, the whole wound with tinned steel wire, to be soldered or brazed in an oven. The whole length of the gun is divided into three sections by steel rings or bands, and forward of the staves the wire is wound directly upon the steel tube. It weighs 30 tons; is 27 feet long; the projectile weighs 600

pounds. The staves were annealed at the Washington Navy Yard. They were 24 feet long, four inches square, and weighed 1,290 pounds each.

The tension of the wire of the Woodbridge gun is adjusted and automatically regulated by a wire-tension apparatus patented by Dr. Woodbridge in 1885. The tensions of winding for the different layers are intended to give, when the interior pressure shall reach a little more than 80,000 pounds per square inch, an extension to the wire overlying the chamber, in all its parts, equal to that due to a tension of 100,000 pounds per square inch in a "free" wire.

There are two features to the construction which Dr. Woodbridge considers important: to so machine and shape the longitudinal staves as to obtain a condition that will allow the employment of the whole contractile effort of the wire in opposition to the interior pressure, instead of having the resistance of the staves taking a share in it; and to winding wire with a curvature in order to reduce its tendency to unwind if cut. The accomplishment of the former would be accompanied by many mechanical difficulties, while the latter would scarcely seem to meet all the conditions of protection needed against the attack of heavy rapid-fire guns.

The correspondence of G. R. Lindsay and Lieutenant Whistler in issues of the New York *Times* of March 31 and April 5, 1891, relating to a prototype of the Brown wire-wound gun having existed thirty years ago, led me to look into the early histories of gunmaking for a segmental tube gun.

To show that the principle of using longitudinal segments or bars strengthened transversely is not new, I have presented some sketches of firearms of the period of 1330, taken from an *Elementary Treatise in the Forms of Cannon and Various Systems* translated in 1832 from the French of Prof. N. Percy, of Metz. In describing them he says: The first firearms, which were called bombards and cannon, were fabricated of iron. These arms were very short and of a great caliber, and were made of bars of iron arranged in a cylindrical form and bound together by bands of the same material. They projected pieces of iron and stones, and were fired under great angles. Subsequently they were forged in a single piece, and among the most remarkable of this period, some had outside and inside the form of a frustum of a cone (Figures 18 and 19), the small diameter corresponding to the breech which terminated in a conical screw (Figure 19); others had

the form of a cylinder, or were reinforced throughout a great portion of their length towards the muzzle. Some of these had a chamber for powder, and their reinforce extended throughout the length of the bore (Figures 21 and 22); the bore was eight times the diameter in length, which was 13″; the width of the chamber was one third of the

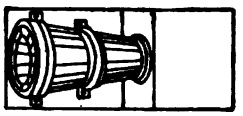

FIG. 18.

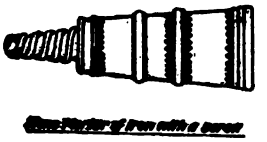

FIG. 19.

FIG. 20.

diameter of the bore, and the depth of it four thirds. All these arms were strengthened by a swell at the muzzle and breech, and by bands at different intermediate points. They had neither trunnions nor handles. According to Thieroux, the first cannon were conical and shaped like an apothecary's mortar or vase (Figure 20); they were called mortars, vases, or bombards. The first change was to a chambered gun with a cylindrical bore, but the chamber was of a less diameter than the bore (Figures 21 and 22). Because these cannon fired stone projectiles they were called *perrieres*. They were made of iron bars bound together with bands like a barrel.

Mr. Brown claims that the fundamental principle of his gun lies in the segmental tube and not in the wire wrapping. He has never

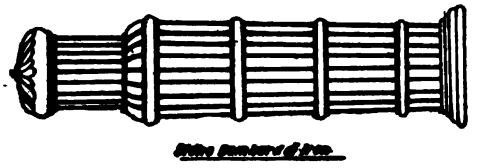

FIG. 21.

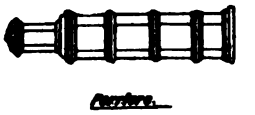

FIG. 22.

asserted that he was the inventor of the wire gun, nor that the use of the segmental tube was new; but he believes that the idea of subdividing a core for the purpose of obtaining special elasticity is original with himself, and that thereby it is possible to set up such a high degree of initial compression that even under the highest powder pressure the compression at the surface of the bore will not be reduced to

zero. To present the views of the advocates of this principle of gun-making, I have taken the following description from the literature of Lieutenant Whistler, the company's engineer:

"The Brown Wire Gun (Figure 23) consists essentially of a segmental core wound with wire under such tension that the compression between the longitudinal segments of the core induced thereby will be more than sufficient to resist all ordinary powder pressure. The longitudinal segments are primarily held together by a breech and muzzle nut screwed on hot, with the proper degree of shrinkage, so that the tension of the nut and adjoining wire will be the same after winding. The wire is wound between the nuts under a high degree of tension, and anchored by a special device. The trunnions are not attached to

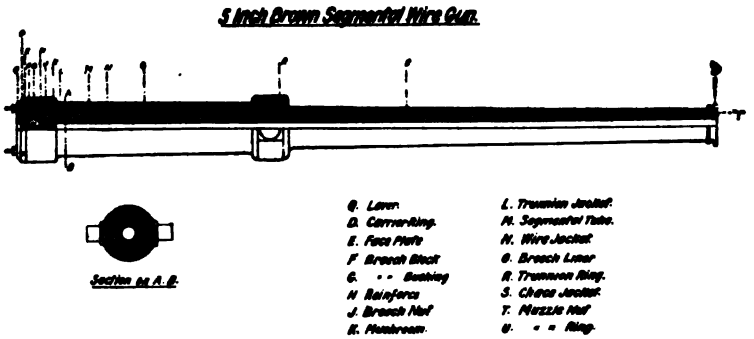

FIG. 23.

the core or body of the gun but to an outer trunnion jacket, which jacket is attached to the gun proper by means of the breech nut. By this means the recoil is transmitted to the trunnions through the breech nut and jacket, and the core or body of the gun is thus relieved from the major part of the longitudinal thrust due to powder pressure upon the bottom of the bore. The gun itself is free to expand longitudinally within this jacket, which is attached only to the breech nut. The essential feature of the gun is, of course, the segmental core. This core consists of a number of longitudinal steel segments, the number being so regulated that the maximum thickness of a segment shall not exceed one half inch materially. . . . The chase jacket consists of a series of interlocking hoops shrunk on over the wire extending from just in advance of the trunnions to the muzzle, the entire jacket being

held in place by a muzzle nut, the thickness of which and the amount of shrinkage being so adjusted that when completed the compression produced by the built-up muzzle nut will be the same as that produced by the wire and chase rings."

During the progress of the work, which has been extended over a period of three years, mechanical difficulties and the results of the trials of experimental cylinders representing sections of the powder chamber gave reason for decreasing the number and increasing the size of the longitudinal segments and the necessity for the insertion of a lining tube to prevent the entrance of the powder gas between the segments, which, in the case of one of the experimental cylinders, was so great as to cause marked discoloration at the joints. The lining tube was inserted under initial tension and extended to about five or six calibers in advance of the front end of the chamber. This tube can be removed and replaced by a new one whenever it becomes too much eroded for service. Recalling the unfortunate experiences of the Maitland half-liners in England, this would appear to be but another invitation for the erosive action of the powder products.

The advantages claimed for the system are: "1. In consequence of the small weight of each of the component parts of the gun, crucible steel can be used economically. 2. The small size of the segments and the ingot from which they are rolled admit of being carefully cast and uniformly forged, so as to insure uniformity of metal, and of being thoroughly annealed. 3. They can be readily rolled into shape; that is, the method of construction is exceedingly economical. 4. They can be thoroughly and conveniently inspected. 5. The size and thinness of each segment insure a thorough and uniform tempering and annealing, if temper be considered desirable. 6. The size of the segments admits of readily setting up conditions of special elasticity by cold work. This latter feature is by far the most important one in this system of construction, as it renders it possible to use a character of steel far beyond anything heretofore employed in the core of a gun."

If the segments compressed by the full elastic strength of the wire present an interior surface that can withstand the erosive action of the powder products, we must admit that Mr. Brown has supplied a method of forming the bore of the gun which has decided advantages; but if recourse has to be had to a liner to resist erosion we return to a core that will not sustain the full elastic strength of the wire, and it prob-

ably will be more economical to use a steel tube of suitable dimensions than a combination of segments and thin liners, unless these liners, like the segments, are cold drawn, and thus by a great amount of mechanical work rendered impervious to the serious ravages of the powder products.

Even if the 5″ experimental gun now approaching completion successfully meets all the conditions that its projector and engineer claim for it, it will still remain to be proved if all the mechanical conditions can be met in guns of larger calibers. The experiment is an interesting one, and if the type is not absolutely new the method of construction is, and all the theory in connection with it is being ably and fluently presented.

Through the courtesy of the John A. Roebling's Sons Company, of Trenton, New Jersey, Messrs. R. H. Wolff & Co, Limited, of Harlem, New York City, and First Lieut. G. N. Whistler, of the United States Fifth Artillery (the engineer of the Brown Gun Company), I am able to show you samples of the wire used in the construction of the Woodbridge and Brown guns.

Dr. Woodbridge and Lieutenant Whistler have also been good enough to answer freely many of my recent questions. They, together with Captain Crozier, have shown much interest in your desire to have this subject presented to and discussed by your Institute, and I regret exceedingly they could not be present this evening to answer any questions that my lecture may have suggested.

It is evident from the various plans and suggestions I have called to your attention that very few attempts were made to apply the individual parts to a service of their individual and separate capacities, and that the attempts to unite in one mass the integral parts resulted in impairing the integral strength and a consequent reduction in the strength of the whole. This separation, however, has been successfully accomplished in the Longridge gun (Figure 15) and mortar (Figure 16), and it is being done in the "hooped" system as well.

In the de Brynk construction the tangential strength may be provided by wire-wrapping without interfering in any way with the advantages claimed for it; namely, turning the core of the gun upon its main axis when the scoring of any part renders such operations necessary, separating the gun into masses to facilitate transportation and assemblage and to decrease the size of the machinery required for the manufacture of its parts.

All accidents to wire-wrapped guns point to the absence of adequate longitudinal strength. After a careful consideration of the many devices that have been suggested to meet this defect, that of supplying this quality by long forged steel hoops seems the simplest and most effective.

When considering the argument so often presented that there will be a saving of weight, remember that the reduction of weight in the gun must be provided for in carriage and recoil, and that we have now replaced the expression "heavy ordnance" by that of "high power ordnance," because we have gained the power without additional weight of metal, and in many cases by a marked decrease of it. All welding can now be done by electricity; weak spots can thus be avoided and continuous winding easily effected.

When many of the objections to wire-wound guns were raised wrought iron and iron wire were generally employed, and the mechanical means of shaping and machining were more or less imperfect. Whitworth used some steel, and his mechanical devices led the world but were infants in comparison with present appliances.

The advantages claimed for the wire system of construction are:

1. That steel in small sections can be obtained that possesses greater strength than is possible to get in any other form.

2. That each layer can be brought truly to its correct tension.

3. Flaws of manufacture can be easily detected, and if not discovered are confined to that part in which they exist.

4. The parts of the gun are light and can be more certainly and easily produced and assembled.

5. For their manufacture, expensive and complicated plants are not needed.

In comparing the reported results of the tests of the various types we must not forget that these experiments have been carried on in various parts of the world, in places very far distant from each other, under different methods, inventors, and circumstances. In the majority of cases they have required to produce them much special machinery which if employed in subsequent production would materially reduce the cost of the guns turned out. In some cases the inventors have been employed to superintend or advise concerning the construction or the preparation of tools or machinery necessary to carry out their special and in some cases peculiar ideas; all these circumstances

have combined to make the cost of the experimental guns very great. On the other hand, the inventors or advocates in estimating the comparative cost and time of production have given themselves every benefit. As these guns have never become commercial service products on any large scale (I believe Russia has manufactured a larger number than any other nation), it is impossible to make any reliable comparison of their cost and the time required for their production.

The wire-wrapped type had the honor of firing the "Jubilee Rounds" in the Queen's Jubilee Year, and gave wonderful results. On April 16, 1888, was fired at Shoeburyness the first of a series of rounds intended to investigate the conditions attending firing at very long ranges. The gun selected was a 9.2″ gun, made under the direction of General Maitland in the Royal Gun Factories. The weight of the gun was 22 tons; that of the projectile 380 pounds, which, fired with a charge of 270 pounds, gave a muzzle velocity of 2,360 feet seconds. The elevation of the first round was 40°. The projectile fell at a range of about 21,000 yards, or nearly twelve miles. On July 12, at 43° elevation, a range of 21,600 yards was attained, and on July 26, with 45° elevation, the range was 21,600 yards, or about 12.4 miles. The projectile remained in the air about 69.6 seconds, and its trajectory reached a height of 17,000 feet, or about 2,000 feet higher than the summit of Mont Blanc.

Comparing the velocity, however, with a more recent 6-inch quick-firing gun (hooped) a velocity of no less than 2,669 feet has been realized with a 19½ pound charge of cordite.

It is easier for the historian to criticise than for the engineer to prophesy; consequently we should not only be grateful for the failures upon which many of our successes have been based, but also remember that the constructions which subsequently proved so inadequate were marked improvements over those which went before. Further, they should be looked upon and their value estimated from a standpoint and comparison of the periods in which they were suggested. Lecky in his *The Art of Writing History* said: "A fatal and very common error is that of judging the actions of the past by the moral standard of our own age." Scientific accomplishments at present are like clearing-house settlements — completed to-day only to be changed to-morrow.

FIRE-PROOF CONSTRUCTION.

By N. POULSON, of the Hecla Iron Works.

Read February 23, 1893.

The object of the mode of fire-proof construction to be described is to build more economically than is now done. In the present construction, with columns, girders, beams, arches, etc., there is a great waste of material which cannot be avoided. In the arch construction there need not be any waste material, and the material used is used to a better advantage. The construction is as follows: In a building in which the floors are supported upon columns metal arches and their ties are built between the columns in such a way that the strains, compression, and tensile are taken care of in each bay or floor between columns, so that there will be no horizontal thrust on either columns or walls from the floor. The arches are made of bar L or T iron or steel. If the floor is to be supported on four girders or four walls there is placed on the lower flanges of the girder or on the walls a polygon-shaped frame, from the corners of which are sprung metal arches, and where the arches cross each other they are held together with U bolts. The arches will form a metal dome, of which all the strains from the arches are taken up by the polygon ring, so that there will be no horizontal thrust on the girders or walls from the arches in the floor construction.

This completes the metal part of the construction. The plaster or cement part of the construction is made as follows: For a plain ceiling with the metal arches showing underneath there are placed in the spaces between the arches air-cushions, which are pressed up against the metal arches from underneath; the air-cushions will then form a dome in each space between the arches; on top of the air-cushion is spread plaster of Paris or cement; after it has set the air-cushions can be removed and the under side of the ceiling will be

finished, showing a groined ceiling. But if the metal arches are to be covered with plain or ornamental moldings they are first put up and then the air-cushions inserted between them. If the domed panels are to be ornamental a flexible mold is placed on top of the air-cushion, and the flexible mold may be made of rubber, gelatine, or

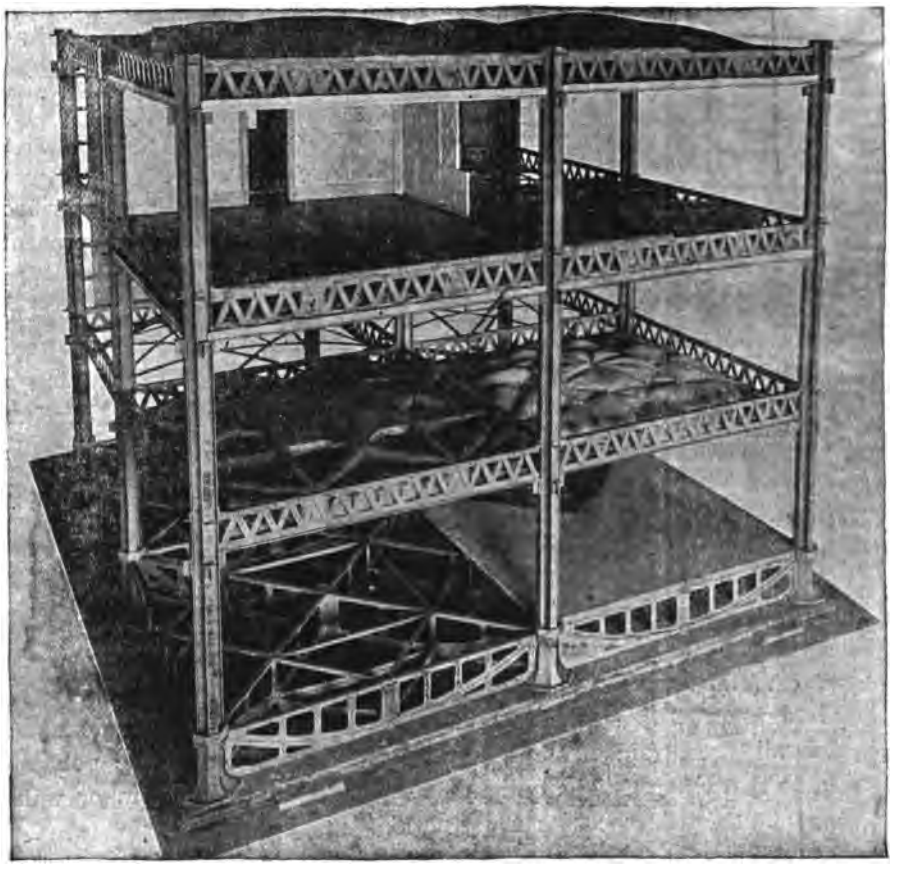

FIG. 1.

any such material. After the under side of the ceiling is finished there are constructed on top of the iron arches cement arches or ribs. They are formed by placing two boards parallel with the metal arches five or six inches apart; the space between the boards is then filled with concrete; in these ribs may be left circular holes through

which hot air may circulate and thereby heat the floor. After the ribs are made and the boards removed, wire and wire netting are

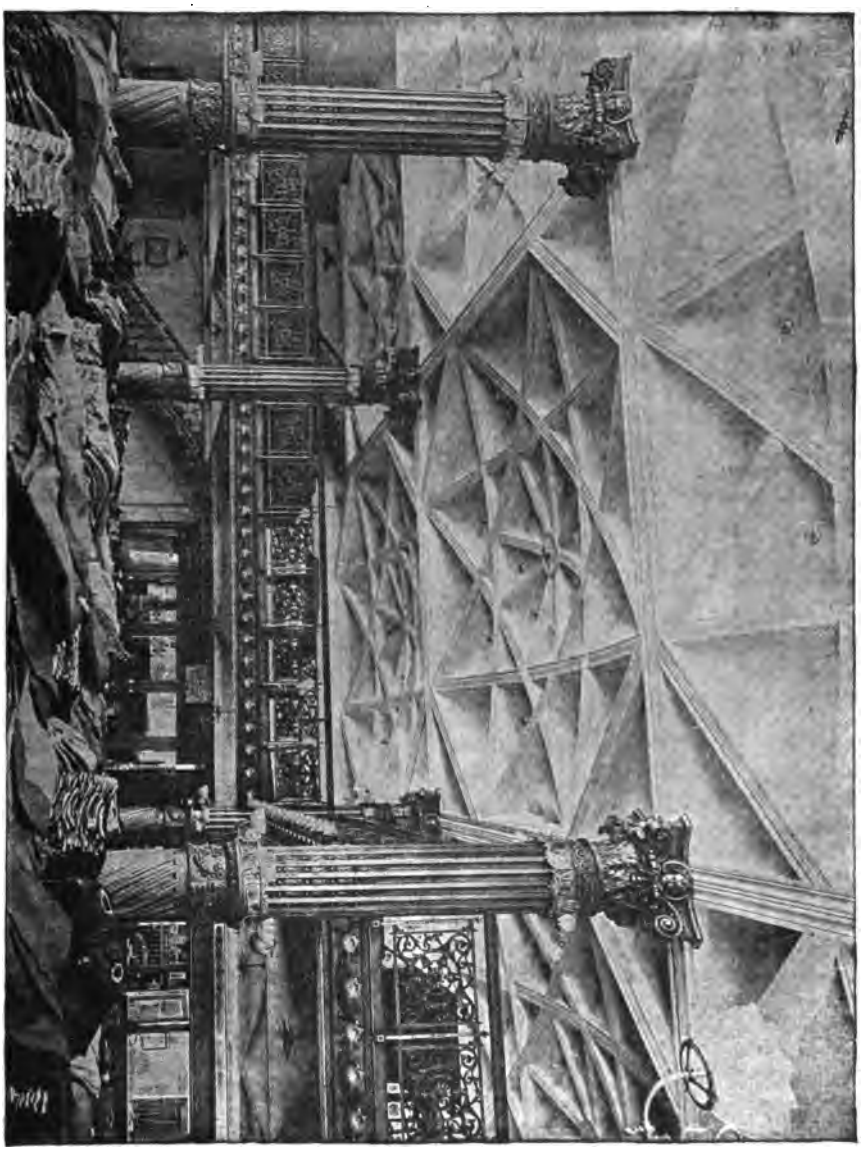

FIG. 2.

stretched over the cement ribs, and on top of the wire netting is spread concrete about three inches thick. This finishes the floor, except the finished floor of wood, tile, or cement.

Let us compare the cost of this construction with that of the usual fire-proof floor construction, composed of girders, beams, brick

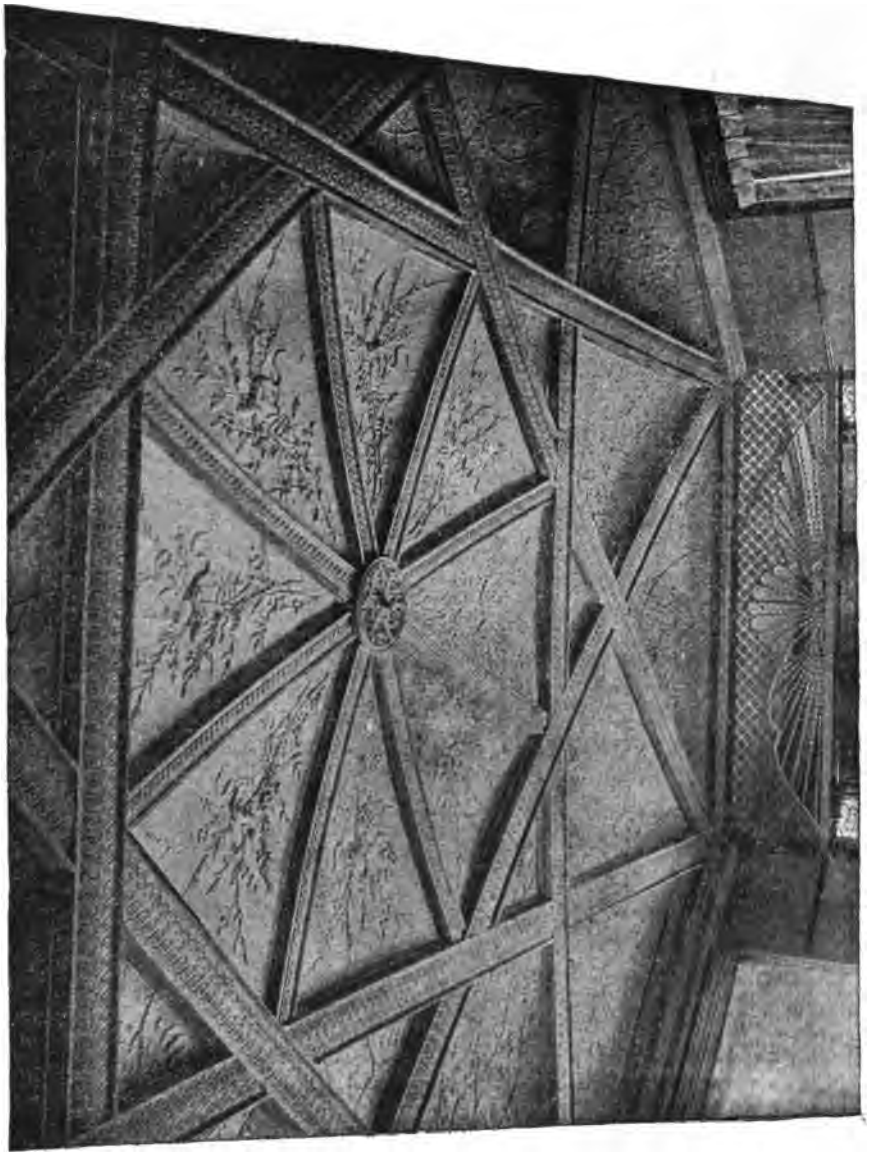

FIG. 3.

arches, etc., in which there is a great waste of material. In the case of a floor constructed of beams, girders, etc., to carry 150 pounds per square foot, the load is first supported by the beams, by them trans-

ferred to the girder and from the girder to the column; that is, the same load is carried twice before it reaches the column. The brick

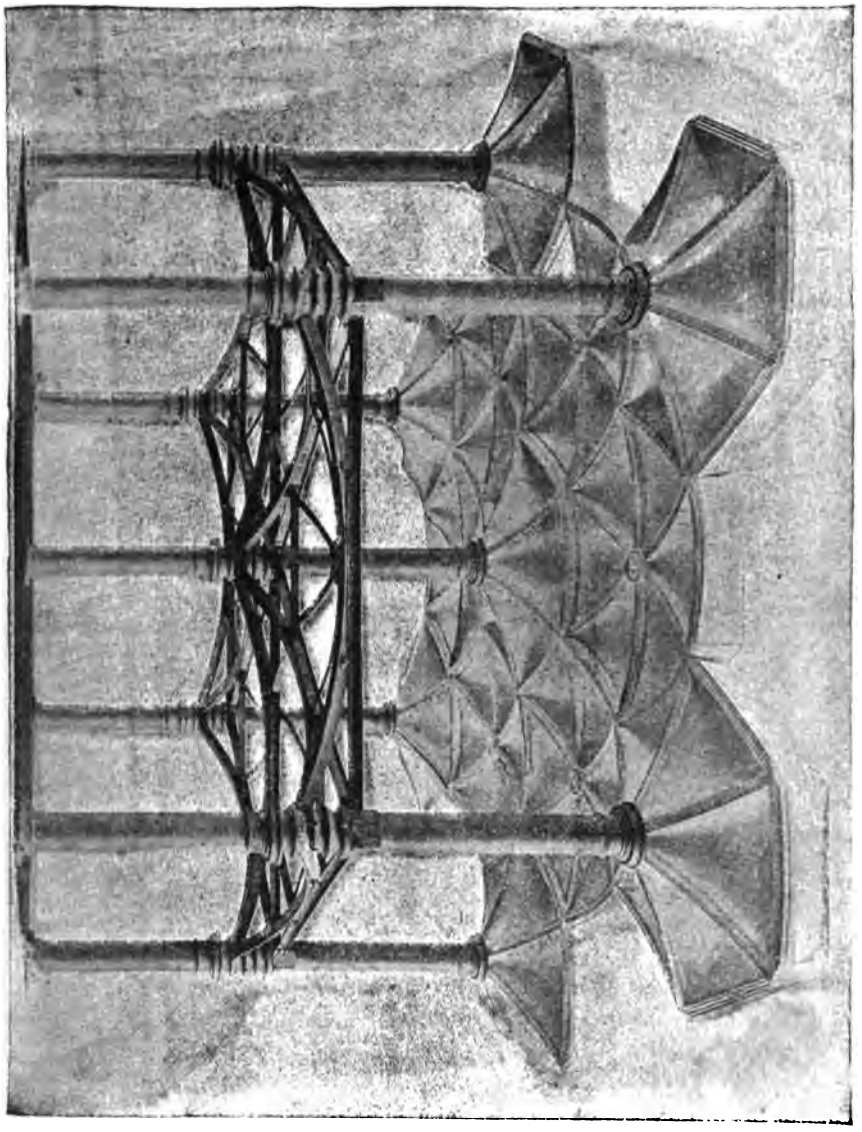

FIG. 4.

arches, filling over them, plastering, etc., have also first to be carried by the beams and then by the girder; that is, for supporting a load of 150 pounds there has to be provided metal sufficient to carry 450

pounds. If the load of 150 pounds was only carried once, and there was no dead load of brick arches, etc., it would only cost 33.3 cents for iron where it now costs $1.00 to support the resultant load, which

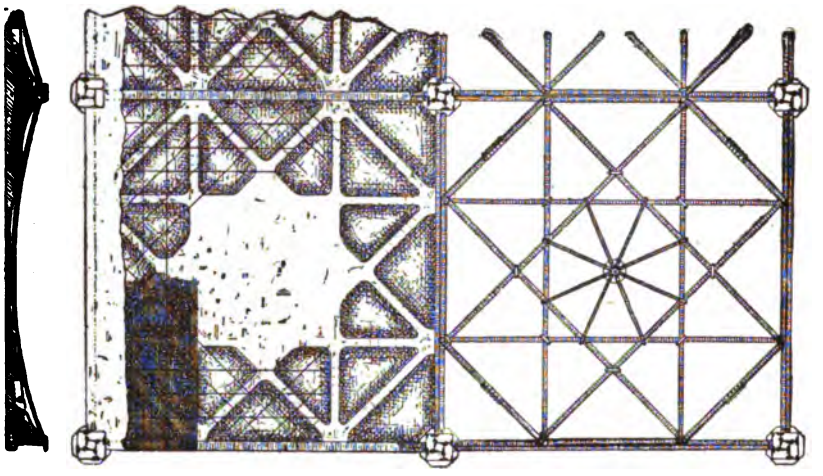

FIG. 6.

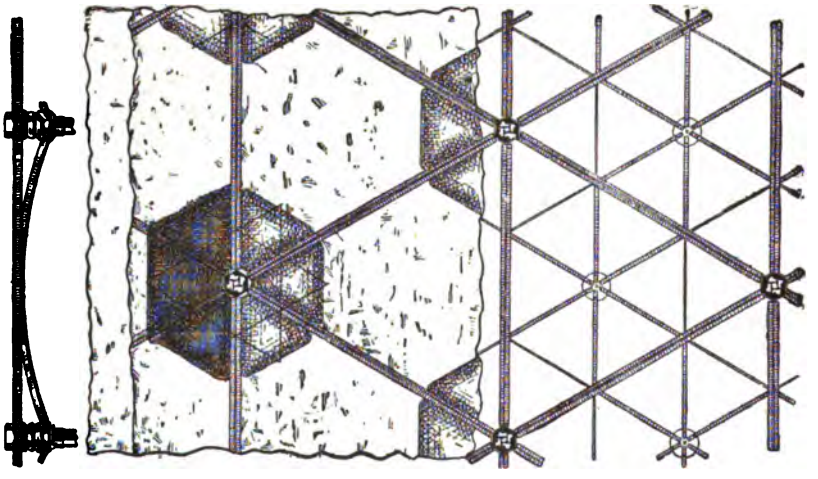

FIG. 5.

is equal to three times as much load required to be supported, and if the iron beams could be made with the web lighter towards the center and the flanges lighter towards the ends of the beam, there could be saved of the metal in the beam at least 10 per cent., without

reducing the strength of the beam, which would reduce the cost to 30 cents; if there was used for supporting the load bar L or T iron instead of beams, the cost could be reduced 20 per cent., as the bar

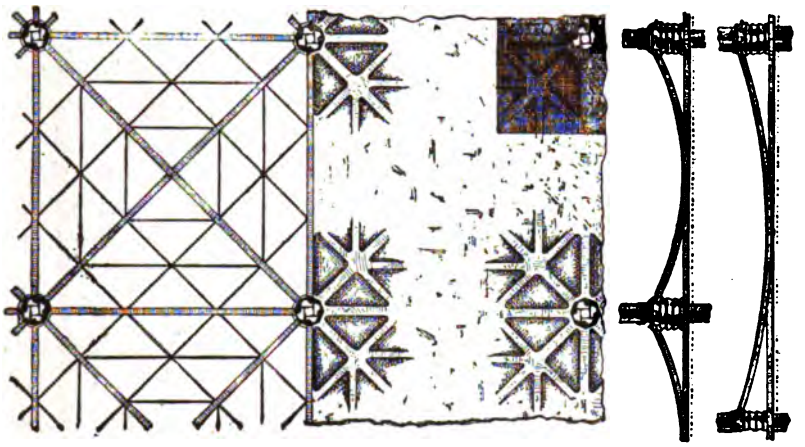

FIG. 7.

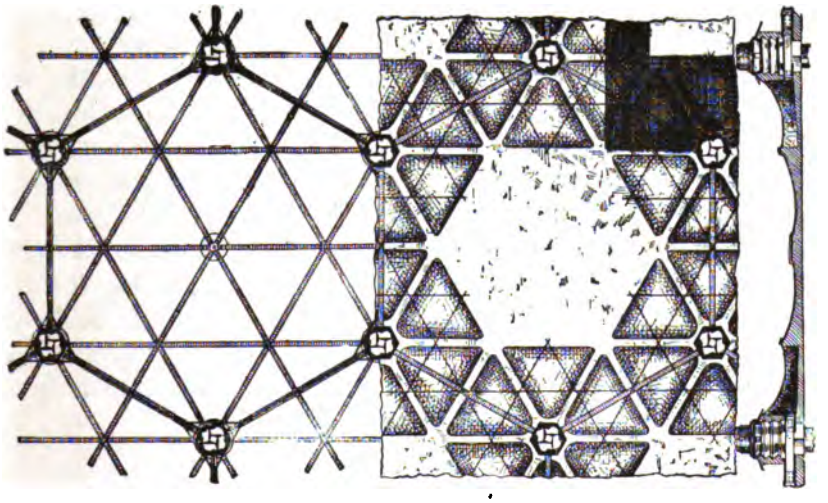

FIG. 8.

L or T iron costs 20 per cent. less per pound, which would make the cost 24 cents. If the above is calculated for a floor with 12″ beams, by making the beam 24″ high instead of 12″ the same amount of iron will carry twice as much, or the amount of iron could be reduced

one half, which would make it cost 12 cents, or if made 36 inches high it would reduce the cost of iron to 8 cents instead of $1.00. The above conditions cannot be met by the beam and girder construction, but can by the arch construction; there the dead load is self-supporting; the load is only carried once. Bar L or T iron is most suitable for the construction of the floor, and can have two or three feet of rise without reducing the cubic air space in the room below.

The cement and plaster part of the construction will also cost less than the usual brick arches, because there is less material used and it is of less costly nature; and furthermore the labor is quickly performed, as it merely consists of spreading the materials in their proper places.

The columns are made of wrought iron or steel, and are continuous from the foundation to the roof, but diminish in amount of materials upwards in proportion to the loads they have to support. In starting at the foundation with a column made of four 12″ heavy beams, after one or more stories the beams can be reduced to 12″ light beams; after that to 12, 9, and 6 inch channels. The horizontal joints are all spliced joints, so that the columns form practically one column from foundation to roof, thereby making the columns much stronger and stiffer than with the same amount of material in a number of short columns placed one on top of another. The continuous column is also more economical to make, as the metal can be of a uniform length and holes punched alike in each piece, so that a beam or channel cut to uniform length will fit in any column. The only place where there will be any waste is at the top of the column, where they may have to be cut to irregular lengths. This way of building a column has a great advantage, as it leaves four continuous recesses from the foundation to roof, which space can be utilized for pipes and wires. If the column is made to finish a few inches above the roof, and a removable cap put upon it, pipes may be put in or removed from the recesses in the column at any time.

LIST OF ILLUSTRATIONS.

No. 1 shows the different stages of the construction described. The basement or cellar shows inverted iron and cement arches with the level floor above, and the space between the arches and the floor can be utilized for piping, wiring, or flues, and can be gotten at at any time. The floor above shows the plaster domes as they are cast over the air-cushions. It also shows the cement ribs for arches running parallel over the iron arch bars. The story above shows the finished floor, and the top story shows the domes of the finished roof. It also shows the continuous iron or steel column with recesses for piping and wiring.

No. 2 shows an interior view of the Smith & Randolph Building, in Brooklyn, in which this construction was used.

No. 3 shows a finished ornamental ceiling. In making this an ornamental gelatine mold is placed on top of the air-cushions.

No. 4 shows a construction in which neither beams nor girders are used, but arches with their ties sprung from column to column, and in the three-cornered spaces between the main arches there are again sprung smaller metal arches. The upper part of the figure shows the under side of a finished ceiling.

No. 5 shows an arrangement of columns and metal arches in triangular construction. It also shows the cement part over the arches, with the wire and wire cloth stretched to receive the cement for the finished floor.

No. 6 shows a square construction with girders between the columns and the octagon dome built between the girders. It also shows the cement ribs and the wire above to receive the cement floor.

No. 7 shows a square construction with no girders, but metal arches between the columns, and with smaller arches in the triangular spaces between the main arches. It also shows the cement ribs and wire and wire cloth to receive finished floor.

No. 8 shows a hexagon construction, with two metal arches springing from each column and the tie rod from column to column so as to form a ring around the hexagon space. It also shows the cement ribs and wire and wire cloth to receive finished floor.

HIGH FREQUENCY ELECTRIC INDUCTION.

By ELIHU THOMSON.

Read March 9, 1893.

It is my purpose in the present paper to give an outline of some experimentation with electric currents of high rate of change or high rate of oscillation compared with the rate of ordinary alternating currents. These latter alternate their direction of flow from 100 to 250 times per second, or the current is composed of waves or pulses reversed in direction at that rate. We therefore speak of 100 to 250 alternations; or, as it requires a double reversal to make a complete wave, we speak of a periodicity or frequency of 50 to 125. Fifty waves per second would be a comparatively low frequency current; five thousand to ten thousand, a moderately high frequency; and hundreds of thousands to many millions may be called high and very high frequencies comparatively speaking. Still, all things are relative, and in the light wave or radiant heat wave we have electrical oscillations of frequencies as great as hundreds of millions of millions per second. If we have two conducting plates separated by an insulating space, and charge one plate positively and the other negatively, we have a simple type of what is called a condenser. The insulation may be air or other dielectric, such as glass or hard rubber. We have in the Leyden jar the earliest form of condenser, and for certain purposes still the best form of this useful electrical device. The charged thunder-cloud layer separated from the earth by a layer of air forms with the earth surface a huge condenser, and the earth strokes or lightning flashes between earth and cloud are the discharges of such condenser. If in a condenser the charge is sufficiently increased in potential difference between the conducting plates or the plates brought near enough together, or if a wire be run from one plate near to the other, a discharge takes place in the form of a spark and there is also an equalization of charge of the plates. The spark simply indicates a breaking

down of the medium separating the plates and its momentary conversion into a conductor composed of hot gases and metallic vapors joining the two plates where the spark existed.

It was formerly thought that in equalizing the charge or combining the positive of one with the negative of the other in such a discharge of a condenser the spark represented a single rush or flow of electricity. Long ago, however, Professor Henry was led to the conclusion that these discharges were of oscillatory character and that the action of discharge resembled that of the release of a bent spring which only comes to rest after a number of more or less rapid alternations or to and fro movements. More recent investigations have settled conclusively the fact that the condenser spark represents in most cases, though not always, an electrical vibration or oscillation of charges, an alternating current of high frequency lasting for a fraction of a second, in which fraction of a second the direction of the current has reversed many times with diminishing force. Prof. J. T. Trowbridge, by means of a rapidly revolving mirror and other ingeniously devised apparatus, has obtained most beautiful photographs of such discharges showing in the most perfect manner the oscillations of current referred to. Now, if a condenser of a certain capacity, as it is termed, be discharged over a short path, the rate of its oscillations of discharge will be greater than when the path or wire through which it is discharged is long. And if the wire forming the path of discharge be of good conducting material and wound into a simple coil of very many turns, the frequency or rate of oscillation of the current of discharge will be much further lowered. Indeed, in this way it is possible to give to the discharge any desired rate within reasonable limits. From a rate of hundreds of thousands per second it may be brought down to less than one thousand. By the addition of the coil in the discharge circuit we have brought into play a property called inductance, which acts to slow the rate of discharge.

If a current be suddenly passed through a coil of wire, it meets with an opposing force which tends to delay its passage, owing to the fact that around the coil and through its axis there must be some work done in producing magnetism in the medium. On an attempt being made to cut off the current, the magnetism in disappearing sets up an action which tends to prolong the current and prevent its change. These are the actions of self-induction, more recently called inductance. An iron core or bundle of iron wires increases the value of the inductance very greatly.

Early experimenters frequently passed Leyden jar or condenser discharges through coils of wire and noted the effects, the chief of which was to flatten or deaden the sharp snap of the discharge. To-day with a sufficiently long coil we may cause the discharge to take any pitch and become audible, if we please, as a musical tone.

Early experimenters, notably Professor Henry, even placed alongside the coils through which condenser discharges were passed other coils and received the inductive discharges set up in the parallel coil, thus realizing in embryo an induction coil, the primary coil of which was given an oscillating condenser discharge, while the secondary currents obtained in the parallel coil were noted by simple means.

In 1877 I made similar experiments in passing the discharge of a number of large Leyden jars through the primary or secondary of a Ruhmkorff coil and noting the effects in the other coil. The effects were in some cases high frequency effects, though scarcely recognized at that time. But we have in the Ruhmkorff coil itself an excellent example of an apparatus in which a charged condenser discharges at a high rate through a primary coil and induces a very high potential discharge in a long and fine secondary coil placed outside the primary.

It has often been stated in the books that the function of the induction coil condenser, which has its conducting foils respectively connected on each side of the break piece which interrupts the current of the battery passing in the primary coil, is simply to prevent spark at the contacts of the interrupter by absorbing or taking up the extra current which would otherwise appear as spark. This is incomplete and erroneous, as may easily be proved.

The ordinary induction coil has its primary coil, its secondary, interrupting contacts for the primary, condenser around them, and battery with rather short conducting wires, and may be assumed to work normally and give a high potential spark between its separated terminals at every interruption of the primary coil and battery circuit.

Now let us extend the wires of the battery to a very considerable length, or coil them in separate open coils, yet keep them of large enough size so as not to weaken the battery current by increase of resistance in its circuit. On working the coil and adjusting the condenser to get rid of spark, we find the activity of the secondary lessened. It can, however, be restored by connecting a large capacity condenser, or better, a cell with plates of lead immersed in dilute sulphuric acid across the battery wires near the coil. Moreover, for a

Ruhmkorff coil to give its maximum effects the condenser chosen for it must have a definite size or capacity depending on the proportions of the primary coil and core and the electro-motive force of the battery. The real object of the condenser is to obtain the benefit of a high frequency reversal in the primary coil, that is, to confer the high period oscillatory character of the condenser discharge on the primary current, and so get enormously increased inductive effects in the secondary wire.

This effect of inducing discharge in the secondary wire depends on a magnetic change or loss of magnetism in the iron wire core or bundle in the center of the coil. Upon the interruption of the primary circuit the condenser receives a charge from the primary wire which instantly discharges itself in the reverse direction through the primary, and as a consequence quickly discharges and tends to reverse the magnetic state of the core. The more quickly the reversal takes place, other things being equal, the longer the spark obtainable from the secondary circuit terminals. Lengthening the wires to the battery delays this reversal by interposing more self-induction, which, as stated above, is a cause of reduced speed or rate of oscillation of the condenser discharge.

As, however, when the lead plate cell is used as a shunt to the battery wires near the coil, the reversal may now be confined to a local circuit including only the primary coil and the shunting cell with its lead plates, and it will be seen that the effect of long battery wires may thus be almost completely counteracted. It does not follow that the secondary discharge of a Ruhmkorff coil is oscillatory even when the primary tends to be so, for the very high resistance of the secondary circuit will probably prevent the flow of more than a single pulse of current in one direction at each break of the primary circuit.

Having stated the conditions under which we may expect to work successfully, we may now be prepared to simplify our apparatus. Let us take a Leyden jar, or battery of jars, charged, say, to give one half inch spark between its terminals, one from the inner coating and one from the outer coating, and interpose a coil of a few turns of wire in the discharge path or circuit. Upon a discharge passing, an exceedingly rapid to and fro current passes in the coil, the turns of which must be kept well apart or a leap from turn to turn will take place in the effort of the current to avoid going around. Now place another coil parallel to the first, and let these be of an equal number of turns,

but well insulated from the first. On passing the discharge through the first coil a similar discharge may be obtained between the separated terminals of the secondary coil.

Let the secondary coil be replaced by one of, say, twenty times the number of turns which the first coil has, and the discharge be sent through the first. In this case it will generally be found that the second coil gives evidence of very powerful induction, but that it requires to be immersed in oil to preserve its insulation. This is done by placing both coils in oil and repeating the experiment. Now the terminals of the secondary coil may yield sparks of several inches in length even though the condenser jars may only give one half inch. But what have we here? Merely a Ruhmkorff induction coil with a condenser charged to 20,000 volts perhaps, as against one charged in ordinary cases to less than a hundred volts. It is no wonder then that we may use a secondary of only a few hundred turns of wire as against one of many thousands of turns in the ordinary Ruhmkorff induction coil and obtain the same or a greater length of spark. I have an apparatus of this kind with ten turns of coarse wire in its primary wound as an open single layer coil, and 300 turns of secondary, also a single layer, both immersed in an oil box. On passing condenser discharges of .20,000 volts in the primary it will give very long sparks from the secondary. The turns of the primary are selected to give the heaviest current and highest rate of oscillation of the discharge with as many turns as possible; in other words, to obtain a convenient maximum. It is inconvenient to charge the condensers and use only a single discharge at a time. To obviate this I have recourse to a modification of a method which I first applied in 1881, that is, to use a dynamo current of alternating character to keep charging the condensers as they are discharged. I found that I could so use the dynamo current as to cause condensers to rapidly charge and discharge over a spark gap, and that a coil in circuit with the condenser needed to have its turns kept apart an eighth of an inch or more, even though the wire was well covered with paraffined cotton. The inductive effect of the coils in the condenser circuits was very high, and I was convinced at the time that we had to deal with discharges of very high rates of change. In applying dynamo currents to the charging of a condenser we may therefore use an alternating current of, say, 75 volts potential and of low period or low frequency, such as ordinary lighting currents, and by an induction coil or transformer raise such potential to, say,

20,000 to 30,000 volts in the secondary winding. This high potential current is now used to charge a condenser of suitable capacity, such as a battery of Leyden jars, the discharge circuit of which includes an open coil of but few turns and a space called a spark gap, over which the discharge must leap. An air jet plays upon the spark gap to prevent a continuous arc forming.

To digress for a moment here, it may be mentioned that with a condenser of two or three jars, and a properly directed air jet or wind blowing on the spark gap, some of the most beautiful imaginable effects of electrical discharge are obtainable. Appearances of beautiful striated flames and networks of fine sparks surrounded by purple fire are easily obtained. Also by putting in circuit with the condenser and spark gap coils of very many turns of fine wire, the rate of vibration may be so lowered as to obtain discharges which whistle continually like the notes of a canary, or which are still lower in pitch, or again so high that the note though strong is at the upper limits of audition.

But to return to the coil of few turns, it will be found that the apparent resistance of even a very coarse wire used in the coil is so great that an incandescent lamp may be lighted between one turn and its neighbor, that, in fact, the opposition to the flow of current is so extraordinary that a considerable length of spark may be obtained in shunt to a few turns. Let us pause to consider why this is. The condenser charge on leaping the spark gap tends to pass a very heavy current through the coil, *i.e.*, to discharge instantly. This involves, however, the instantaneous production of an intense magnetic field in and around the coil, which gives rise to a force tending at first to check the condenser discharge and afterwards to prolong such discharge so that there results an over discharge or a charge of opposite character which again discharges, and so on. But these oscillatory discharges may have a rate of hundreds of thousands per second, or a still higher rate depending on the conditions. Every inch of wire in the coil is as active as a number of feet at lower frequencies.

One of the most curious effects producible is that of balanced induction, as when a double coil is used one inside of the other, the turns of which can be so selected that all of the discharge passes in the outer coil or all in the inner. A departure from a definite relation of turns, relatively less or more, destroys this balance of induction.

The inductive action of the high frequency discharges in ques-

tion is quite intense. Electro-dynamic inductions so intense as to generate potentials of a hundred or more volts to the inch of wire are readily obtained, and of course the reaction or self-induction of such a current sent into a circuit is equally remarkable. Conductors which are so heavy that with ordinary continuous currents an ordinary incandescent lamp would be completely shunted offer such an impedance to these high frequency currents that the lamp is brilliantly lighted across a short heavy loop, an experiment due to Mr. Tesla, an early worker in this field. A single turn of wire of, say, six or eight inches diameter of circle, used as a secondary to a few turns used as a primary, suffices to brilliantly light a lamp connected in the circuit of the turn. Such experiments may be modified in many ways.

In experimenting with apparatus in which a very few turns of wire were used with the condenser discharge as a primary, and in which a few hundred turns were used as a secondary, it was found to be necessary to immerse the coils in oil to insulate them and prevent escape of the currents induced in the secondary. These experiments have developed the curious fact that while ordinary oils are capable of resisting puncture by high potentials of ordinary alternating currents when the thickness of the insulating layer of oil is to the air layer as about 1 : 3 or 1 : 4, the relation when high frequency currents are used is about 1 : 40. It was also found that the cleaner the oil or more free from suspended particles the more uniform its insulating power or resistance to puncture and the greater the potential needed to puncture it. Another curious fact was brought out, namely, that under oils discharges between balls or plates took place more readily and through greater distances than between points — a fact which is exactly contrary to what is found in the case of air.

It has recently been found that while alcohol is a partial conductor for ordinary currents it is an insulator for very high frequencies, and it appears probable that water itself, and perhaps ordinary electrolytes, such as a solution of salt, would behave as nonconductors with a sufficiently high frequency applied to them. By taking advantage of the inductive effects of a condenser of considerable capacity discharged across a spark gap or a pair of gaps in series, upon which a blast of air is kept blowing, and having also in the circuit of the discharge say 15 turns of coarse wire wound into an open coil used as a primary, with a secondary coil of a single layer of some hundreds of turns of finer wire wound on an insulated frame or support, and with the pri-

mary immersed in an oil vat, remarkably high potentials are readily obtained. The coils are separated by oil, the thickness of layer depending on its resistance to puncture by the discharge.

In the largest apparatus yet constructed the primary coil has 15 turns wound double of No. 6 wire, and the turns having a diameter of 22 inches, while the whole coil is spread to an open helix of 28 inches in length; weight 14 pounds. The secondary coil is wound on a hard rubber open frame, and consists of 580 turns of No. 26 wire, the turns having 17 inches diameter, and the coil being 28 inches long. It contains about 2,600 feet of wire; weight $2\frac{1}{4}$ pounds. These coils are immersed in an oil vat of wood and are held concentrically. The terminals of the fine wire are carried out at the ends of the oil vat in the center of a trough about 5 inches square filled with oil, and the conductor is so kept covered with oil to the very end where it is at last exposed. In some experiments with this coil, with the terminals 64 inches apart, it gave torrents of sparks between them. The sparks were blue-white, and from the terminals branching forked discharges took place in all directions to distances of two or three feet. These sparks are by far the longest ever produced artificially, and the apparatus is so simple and of such slight cost that it is extremely doubtful whether any such large Ruhmkorff coils as the Spottiswoode coil, with its 280 miles of secondary wire, will ever be made again. With the simple oil insulated apparatus described a torrent of sparks (250 per second) was obtained. Heavy glass plates or slabs of other insulating materials are readily punctured, and where the discharge does not puncture but spatters over and around the slab the effect is very beautiful and impressive. Hard-wood plank is perforated and set on fire, sticks are splintered, and the known effects of lightning are reproduced in a very complete way.

The development of ozone in the neighborhood of the apparatus is very great, and soon renders the air pungent and irritating. It appears from the experience gained up to this time with the apparatus that it would be possible to produce apparatus on similar lines capable of developing electric potentials sufficient to leap the space between electrodes twenty or more feet apart.

Especially striking, also, are the experiments which concern the passage of these high frequency discharges through a person's body. Even with frequencies not higher than two thousand per second the late Dr. Edward Tatum found that a dog could support a greater cur-

rent than if the current were continuous in character. With still higher frequencies it is probable that greater immunity would exist.

By holding a metal or carbon rod in the hand while standing on the floor or seated near the high potential apparatus, and providing small wires and bits of wood suspended from one terminal of such apparatus, while the other is connected on the other side to a length of wire or a metal plate, sparks may be taken between the wire or suspended objects and the rod held in the hand, and these may be a number of inches in length in an apparently continuous stream. In this way the small wires may be melted down and objects set on fire, pieces of wood charred, etc., by the currents passing in the spark and through the person's body. Notwithstanding the striking effects, the current is scarcely felt at all.

By the use of vacuum tubes and plates or wires extending from or connected to the terminals of his high frequency coil, Mr. Tesla has produced very brilliant effects of illumination of such tubes. In fact a vacuum tube may be used to explore the high frequency electrostatic field around the high frequency apparatus very much as a compass-needle may be used to explore a magnetic field. It has long been known that a Geissler tube lying near a powerful Ruhmkorff coil in work would frequently become luminous, but the high frequency apparatus produces all effects obtainable with a powerful Ruhmkorff coil in far greater intensity.

It may be asked why in the construction of the high potential induction apparatus I have selected a primary of only 10 or 15 turns. In answer it may be said that it was found that while a greater number of turns would naturally give a greater magnetic effect, and therefore greater magnetic change and more powerful induction, yet the use of such greater number would so lower the frequency in view of the desirability of using condensers of rather large capacity relatively as to lose more than was gained. The induced electro-motive force depends on the rate of change or frequency, as well as on the total field undergoing change. Again, should we attempt to run up the frequency by still further diminishing the turns, what we so gain is lost in diminished ampère-turns or magnetic field, especially as there will always be a certain impeding inductance in the connections or leads from the condenser plate to the primary coil. This inductance should be cut down as much as possible by the use of wide strips for such connections and by a non inductive arrangement of them where it is possible.

It may be remarked in conclusion that, as concerns the secondary of the apparatus as well as that of a Ruhmkorff coil, the effects are not purely electro-dynamic, but are modified by capacity. In every coil in which high potentials are generated, especially at high frequencies, the electrostatic induction of the turns of the secondary upon each other and upon surrounding or adjacent conductors, particularly the primary coil parallel to the secondary, are not to be neglected. From the center turns of the secondary outward to the terminals a progressive elevation of potential exists before the passage of a discharge. This brings into play the capacity of the secondary turns, as parts of a condenser receiving charge, and with high potentials this capacity is quite considerable. From the fact, as developed by my experiments, that such high potential apparatus needs to be carefully proportioned or otherwise the effects will be disappointingly small, I am satisfied that such relations should exist between the inductance and the capacity of the secondary conductor as to keep it in phase with the primary oscillations, and any condition which produces an undue positive or negative lag in the secondary phase will weaken materially the effects. It remains simply to state that of course the medium surrounding the apparatus is traversed by rather long Hertzian waves, which could readily be detected by proper resonators, and that further the apparatus can be used to charge the Hertz apparatus instead of an induction coil. I should anticipate that the production of the Hertz effects in a more continuous and vigorous way than hitherto would follow the adoption of these modern means for securing high potentials.

INFLUENCE OF THE INTRODUCTION OF A SULPHONIC GROUP UPON THE POWER OF A DEVELOPER.

By A. A. NOYES and W. K. GAYLORD.

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In making some experiments with para-amido phenol sulphonic acid, our attention was called to the fact that para-amido phenol is a photographic developer, and it seemed to us that it would be interesting to investigate the developing qualities of the sulphonic acid, especially as no accurate statements in regard to the influence of the sulphonic group upon developing power seem to have been made heretofore. The only mention we have found is that by A. and L. Lumière.[1] "Sulphonating does not appear entirely to destroy the developing power."

Preliminary experiments showed that para-amido phenol sulphonic acid is indeed a developer, and we have compared its action with that of the para-amido phenol itself. We exposed gelatine dry plates equal lengths of time under a negative in constant artificial light, and developed them partly with solution A and partly with B, which contain equivalent weights of para-amido phenol and its sulphonic acid as follows:

A. Para-amido phenol.		B. Para-amido phenol.	
Hydrochlorate	.05 g.	Sulphonic acid	0.7 g.
Sodium sulphite	8.0 g.	Sodium sulphate	8.0 g.
Sodium carbonate	2.2 g.	Sodium carbonate	2.2 g.
Water	100 cc.	Water	100 cc.

In one experiment the image appeared in solution A in 8 seconds, while in solution B 40 seconds were necessary. In the first case development was complete after 2 minutes; in the second only after $4\frac{1}{2}$

[1] Jahrbuch für Photographie, 6, 92.

minutes. From these figures it appears that the sulphonic acid is much less powerful in its developing action than the amido phenol itself. This result was confirmed by other experiments with plates exposed in the camera, the sulphonic acid taking always much more time for development than the amido phenol. Moreover the negatives so obtained are much weaker, and only by using much more concentrated solutions (*e.g.* 4 g. per 100 cc.) of the sulphonic acid and continuing development for a long time did we obtain fairly good negatives. Attempts to hasten the action by addition of more alkali resulted in negatives too weak.

From these experiments we conclude that the introduction of the sulphonic group has a greatly weakening influence upon the developing power of amido phenol. An investigation of other sulphonic acids in this direction would be of interest, since it is probable that the sulphonic group will be found to have a different effect according to its distance from the amido or from the phenol groups. A good example would be eikonogen (amido naphtol sulphonic acid) and the corresponding amido naphtol.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
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ELECTROLYTIC REDUCTION OF NITROBENZENE IN SULPHURIC ACID SOLUTION.

BY ARTHUR A. NOYES AND ARTHUR A. CLEMENT.

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WHEN we undertook this investigation no successful experiments on the electrolytic reduction of nitrobenzene had been made. Within the last few months, however, several investigators have occupied themselves with this subject. Haeussermann[1] dissolved nitrobenzene in alcoholic soda, and in alcohol containing sulphuric acid, and obtained in the first case hydrazobenzene, and in the second, benzidine sulphate, as products of the reaction. By the electrolytic reduction of nitrobenzene-sulphonic acid in aqueous solution, however, he obtained m-sulphanilic acid. Elbs,[2] by interrupting the reduction before it was completed, obtained azoxybenzene and azobenzene in alcoholic soda. He found, remarkably enough, that anilin was formed by the reduction of nitrobenzene dissolved in alcohol acidified with sulphuric acid, when zinc was used for the cathode. Gattermann and Koppert[3] by using fairly strong sulphuric acid as the solvent obtained p-amido-phenol sulphate as the product. Our experiments were similar to theirs. We used, however, concentrated sulphuric acid, and obtained para-amido-phenol-sulphonic acid.

Our method was as follows: We dissolved 50 grams of nitrobenzene in 200 of concentrated sulphuric acid (1.84 spec. grav.), and placed in this solution a large platinum electrode and a porous cup containing strong sulphuric acid and a smaller platinum electrode. The outer vessel was surrounded with an asbestos mantle, and a current of about 3 amperes (potential 5 volts) was passed through the solution for 15 hours. The temperature remained between 80° and 90° C without application of external heat. The solution soon became deep blue, and remained so to the end. The sulphuric acid in

[1] Chemiker Zeitung 17, 129, 209.
[2] Idem, 17, 209.
[3] Idem, 17, 210.

the porous cell was partially drawn out by osmotic action; the remainder became gradually strongly fuming, owing to the decomposition of the SO_4 ion at the anode into SO_3 and oxygen and the solution of the former in the sulphuric acid. The specific gravity (at 20° C) rose in one experiment to 1.94. It is better, however, to dilute the acid in the porous cup from time to time, as otherwise the resistance becomes very great.

The product of the reduction is isolated by diluting the contents of the vessel with water and filtering. A greenish black mass remains on the filter. This is treated with a solution of caustic soda, and the residue of sulphur and carbon is filtered out and the filtrate neutralized with hydrochloric acid. A grayish or bluish white precipitate forms, which can be further purified by redissolving in alkali and reprecipitating with acid, or by crystallization out of hot water. This body proved to be a sulphonic acid almost insoluble in cold water, alcohol, and ether. It reduces silver nitrate solution in the cold with the production of a purple color; and the solutions of its salts turn brown rapidly in the air. It contains water of crystallization, which is entirely expelled at 100°, and decomposes at a high temperature without melting. An analysis showed it to be amido-phenol-sulphonic acid.

	Found.	Calculated for $C_6H_3(NH_2)(OH)(HSO_3)$.
C	38.11	38.09
H	3.87	3.70
N	7.06	7.41
SO_3H[1]	42.79	42.33

From its properties it is plainly the p-amido-phenol-o-sulphonic acid.

The yield from 50 grams of nitrobenzene amounted in three experiments to 30 grams of the anhydrous acid or 40 per cent. of the theoretical. Special experiments showed that the yield was smaller when two parts of sulphuric acid instead of four were used for one of nitrobenzine. The result was also less favorable at a lower temperature (50° – 60°). Above 100°, however, charring occurs.

Gattermann and Koppert diluted the sulphuric acid solution of the nitrobenzine with as much water as could be added without precipitating the nitrobenzene; and they obtained no sulphonic acid, but the

[1] Determined by titration with alkali.

sulphate of the para-amido-phenol. It is only possible to add about 4 grams. of water to 150 of sulphuric acid without causing precipitation, but this is sufficient to prevent entirely the formation of the sulphonic acid, as we confirmed by experiment.

It is worthy of note that Brunner and Kraemer[1] have also obtained p-amido-phenol-sulphonic acid by heating nitrobenzene with resorcin and concentrated sulphuric acid. In this case the resorcin evidently played the part of the reducing agent.

We have also studied the ease with which the sulphonic group can be broken off. This takes place quantitatively when the acid is heated to 170° in closed tubes with concentrated hydrochloric acid. The temperature at which the decomposition sensibly begins was determined by Mr. L. S. James to be 150° – 155°. The amido-phenol-hydrochlorate separates out in fine large white crystals on cooling, as it is only slightly soluble in concentrated hydrochloric acid..

We are now investigating the reduction product of dinitrobenzene.

April, 1893.

[1] Berichte der deutschen chemischen Gesellschaft, 17, 1867.

REMARKS ON THE DEDICATION OF THE NEW SCIENCE AND ENGINEERING BUILDINGS OF McGILL UNIVERSITY, MONTREAL.[1]

By FRANCIS A. WALKER, LL.D.

I PRESENT the heartiest congratulations of the Massachusetts Institute of Technology to the officers and teachers of McGill University, and especially to Dr. Bovey, on the fortunate completion and the present auspicious dedication to their destined uses, of these commodious and superbly equipped laboratories of physics and engineering. The distinguished position which this university has long held in science and the applications of science to useful arts cannot fail to be greatly advanced as the result of these noble benefactions of Mr. McDonald.

The growth of scientific and technical schools on this continent during the past thirty years has savored of the marvelous. In part, it has been due to the changed ideas and the transfigured ideals of the American People; in part, to the recognized need of greater skill and more of scientific knowledge for the development of the natural resources of the continent and for the direction of its growing enterprises. In this movement of the age, even the older institutions have been compelled profoundly to modify their traditional courses of study, substituting scientific and even technical instruction for much that was formerly deemed essential to a liberal education.

Of the reluctance, and even resistance which this movement has encountered from many who deservedly held high places in the old educational order, I would not speak with harshness. The notion that scientific work was something essentially less fine and high and noble than the pursuit of rhetoric and philosophy, Latin and Greek, was deeply seated in the minds of the leading educators of America a generation ago. And it has not even yet wholly yielded to the demonstration offered by the admirable effects of the new education in training up young men to be as modest and earnest, as sincere, manly, and

[1] February 24, 1893.

pure, as broad and appreciative, as were the best products of the classical culture, and withal, more exact and resolute and strong. We can hardly hope to see that inveterate prepossession altogether disappear from the minds of those who have entertained it. Probably these good men will have to be buried with more or less of their prejudices still wrapped about them; but from the new generation scientific and technical studies will encounter no such obstruction, will suffer no such disparagement.

Another objection which the new education has encountered is entitled to far more of consideration. This has arisen from the sincere conviction of many distinguished and earnest educators that the pursuit of science, especially where its technical applications are brought strongly out, loses much of that disinterestedness which they claim, and rightly claim, is of the very essence of education. For the spirit of this objection I entertain profound respect. I only differ from these honorable gentlemen in believing that the contemplated uses of science, whether in advancing the condition of mankind or even in promoting the ulterior usefulness, success, and pecuniary profit of the student of a technical profession, do not necessarily impair that disinterestedness which I fully concede is essential to the highest and truest education of the man. These gentlemen appear to me to have an altogether unnecessary fear of the usefulness of science. They entertain much of that dread of "Fruit," which Macaulay, in his famous essay on Bacon, doubtless with something of exaggeration, as his custom was, attributed to the old philosophers.

I am willing to admit that, in my humble judgment, many technical schools have erred in addressing themselves too closely to the practical side of instruction; that they have in some degree neglected principles in the study of science, and have borne an undue weight upon mere knacks and labor-saving devices and technical methods. I believe that in doing this they have made a mistake, even from their own point of view, and with reference to the very objects they profess. Moreover, I am free to acknowledge that those who direct many technical schools have made a mistake, in altogether, or nearly so, omitting from their curriculum philosophical as distinguished from scientific, liberal as distinguished from exact, studies. Those technical schools will best accomplish their purposes of usefulness, alike to their students and to the State, which make more of the sciences than of the arts, more of principles than of their applications, and which offer to

their pupils, in addition to the studies which will make them exact and strong, some of the studies and exercises which will help to render them, at the same time, broad and fine.

With only such a subordination of technical and scientific studies as is for the ultimate advantage of the technical professions themselves, and with such a complementing of scientific by philosophical studies as has been indicated, I believe that the work of the student in schools of technology is as fully entitled to be termed disinterested as that of a student in a classical college. In neither class of institutions can or ought the student to be unmindful that his personal success in life and his professional and social position are largely to depend upon the manner in which his work shall be done in college. All that can be asked in regard to any school is that there shall be zeal in study, delight in discovery, fidelity to the truth as it is discerned, high aims, and ambitions which have not sole or primary respect to material rewards. The strong desire to become a useful man, well equipped for life, capable of doing good work, respected and entitled to respect, constitutes no breach of disinterestedness, in any sense of that word in which an educator would be justified in using it with commendation.

The practical uselessness for any immediate purpose of a given subject of study may be no reason why it should not be pursued; but, on the other hand, the high immediate usefulness of a subject of study furnishes no ground from which the educator of loftiest aims and purest ideals should regard it with contempt or distrust. In either case, the question of real import is in what spirit the study is pursued. The most distinguished French writer of to-day on matters of education, writing, too, in advocacy not of physical but of social science, has frankly paid his tribute to the disinterestedness of spirit and loftiness of motive which promote and direct scientific research, even in its most practical applications. "Let us," he says, "pass in review the great founders of modern science and the creators of industry, the Keplers and the Fultons, and we shall be struck by the idealistic and even Utopian tendency peculiar to them. They are, in their own way, dreamers, artists, poets, controlled by experience."

And if, leaving abstract reasoning, we turn to contemplate the manner in which the several professions are practiced in the community, I seem to find corroboration of the view that the study of science and its applications to the arts of life do not tend to produce sordid

character or to confine the man merely to material aims. Every profession has its black sheep and its doubtful practitioners; but, while frankly admitting that there are mercenary physicists and chemists for revenue only, I boldly challenge comparison between the scientific men of America, as a body, and its literary men or even its artists, in the respects of devotion to truth, of simple confidence in the right, of delight in good work for good work's sake, of indisposition to coin name and fame into money, of unwillingness to use one thing that is well done as a means of passing off upon the public three or four things that are ill done. I know the scientific men of America well, and I entertain a profound conviction that in sincerity, simplicity, fidelity, and generosity of character, in nobility of aims and earnestness of effort, in everything which should be involved in the conception of disinterestedness, they are surpassed, if indeed they are approached, by no other body of men.

Let us, then, cheer on every enterprise for the extension of scientific and technical education, without any misgivings as to its effects upon the character and subsequent life of the young men of America, without any fear that they will be rendered sordid in spirit or low in their aims by reason of the practical usefulness of the studies to which they are called to apply themselves. There is a wonderful virtue in the exact sciences to make their students loyal, just-minded, clear-headed, and strong against temptation. Here, no insidious tendencies to mere plausibility, to sophistry, and to self-delusion beset the young and the ambitious. The only success here is to be right. The only failure possible is to be wrong. To be brilliant in error here is only to make the fact of error more conspicuous and more ludicrous. Nothing but the truth, nothing less than the whole truth, this is the dominating spirit of the laboratory, which never withdraws its control over the student to keep him from the false path, which never intermits its inspiration as it urges him onward to the light.

AN INVESTIGATION OF THE EXCURSION OF THE DIAPHRAGM OF A TELEPHONE RECEIVER.[1]

BY CHARLES R. CROSS AND ARTHUR N. MANSFIELD.

Received May 20, 1893.

IN a paper by Messrs. C. R. Cross and H. E. Hayes[2] it was shown that with a magneto-telephone receiver the magnitude of the change in the strength of the magnet when a weak current is sent through the coil increases up to a certain limit as the strength of the magnet is increased, and then diminishes, the explanation of this diminution being found in the approach of the diaphragm toward saturation. The effect of varying the thickness of the diaphragm upon the magnitude of this change was also studied, and it was found that within the limits of the experiments the changed strength of the magnet due to the weak current is greater with thin than with thick diaphragms.

From these results it would naturally be inferred (1) that the amplitude of the vibration of the diaphragm of a telephone receiver would at first increase to a maximum, and then diminish, if the strength of the magnet were continually increased; and (2) that, within such range of thickness of diaphragm as would probably be most suitable in practice, a thin diaphragm is preferable to a thicker one.

The subject has also been studied by Mercadier,[3] by ascertaining the distance at which the beat of a metronome, when transmitted by telephone, just ceased to be audible under different conditions of the receiver as to the thickness of the diaphragm and strength of the polarizing magnet. In Mercadier's experiments the thickness of the diaphragms was varied through a far greater range than in those of Cross and Hayes, but their results are in substantial accordance with his for the same conditions of experiment, although the range of thickness

[1] Read at a meeting of the American Academy of Arts and Sciences, May 24, 1892.

[2] Technology Quarterly, 3, 295.

[3] Comptes Rendus, 1889, 108, 735, 797; 1891, 112, 96.

in the diaphragms used by them was probably too small to produce the peculiar alternations of effect noticed by the former observer.

It seemed to the present writers desirable to verify these conclusions by direct observations upon the motion of the diaphragm itself, and the investigations detailed were undertaken with this end in view. We have thus far considered only the first of the two propositions just stated, leaving the second for future study. The experimental work was completed during the spring of 1891.

As it is very desirable not to have the free motion of the diaphragm interfered with in any way, we decided to make use of the stroboscopic method of observing its vibrations.

The telephone which we employed as a receiver had for its polarizing magnet a bar of Norway iron three fourths of an inch in diameter and eight inches long, which was surrounded by a magnetizing coil consisting of 2,750 turns of No. 18 (B. and S.) copper wire, whose resistance was approximately eight ohms. The line coil surrounding the end of the core was made of No. 36 (B. and S.) copper wire, and had a resistance of 99.5 ohms. The core was capable of being moved longitudinally by means of a screw, so that the distance of its end from the diaphragm could be adjusted. In all of our experiments the distance between the core and diaphragm was kept at $\frac{3}{64}$ of an inch. The strength of the magnet was varied by means of a resistance which altered the current passing through the magnetizing coil.

Since it seemed very doubtful whether the excursion of the diaphragm of the receiver when a current so feeble as that of a telephone was used would be sufficiently great to allow of satisfactory measurement, we decided to employ the alternating current from the secondary of a transformer through whose primary was passed the current from an ordinary alternating current dynamo making 128 complete alternations per second. By the introduction of a suitable wire resistance of variable amount into the secondary circuit the current flowing in it could be reduced to a convenient strength, so that when the magneto-telephone was placed in a derived circuit running from extreme points on this wire the coils were traversed by a current comparable in magnitude with the ordinary telephone current. By operating with a current thus produced, and passing through the coils of the receiver, we hoped to be able to employ a current somewhat, but not very greatly, larger than the ordinary telephone current, so that we might safely assume that the character of the phenomena observed with the former

under the different conditions considered would be substantially the same as those occurring with the latter and weaker current.

The alternating current thus produced, which we will call the "line current," was measured by an electro-dynamometer included in the circuit and placed between the resistance frame and the telephone coil. This electro-dynamometer was constructed especially for the purpose, and was calibrated in the ordinary manner by passing a direct current of known and variable strength through its coils, making the usual reversals to eliminate the effect of the earth's magnetism.

The intermittent illumination needed for the purposes of our experiment was furnished by the sparks produced by a Helmholtz tuning-fork interrupter, making 128 complete vibrations per second. At each vibration, when the style broke contact with the mercury in the cup, a bright spark was produced. The fork was so placed that this flash should illuminate the field of a microscope which was placed opposite, and focussed upon the end of a style carried by the diaphragm of the receiving telephone. The illumination given by the sparks, especially when concentrated by a lens, was abundantly sufficient to enable the observer to see the style as a silhouette against a bright field. The telephone was so placed that the vibration of the style was in a horizontal direction. When no current passed through the telephone the style was of course seen continuously, on account of the rapid recurrence of the sparks. If the rate of alternation of the alternating current employed is exactly 128 per second, thus coinciding in frequency with the sparks, then when this current is sent through the telephone coil, although the diaphragm will enter into corresponding vibration at the same rate, yet the style carried by it will still seem to be at rest when viewed by the microscope. But if the rates are not exactly the same, then of course the familiar stroboscopic effect will be produced, and the style will appear to be in a state of slow vibration, so that the amplitude of the vibration, if sufficient in amount, can readily be measured by means of a spider-line micrometer.

Using an objective having a focal length of half an inch, and an eye-piece of moderate power, and with a very weak magnet in the telephone, we found no difficulty in producing a perfectly measurable vibration with a current of only 5 milliamperes, while with a current of 29.5 milliamperes the excursion rose to fourteen thousandths of a millimeter.

On passing a current through the magnetizing coil alone the dia-

phragm is of course immediately drawn towards the core by a certain fixed amount depending upon the magnitude of the current. Some measurements were made which show the amount of this deflection with increasing values of the magnetizing current. The results of these are given in Table I. The current is given in milliamperes, the deflection in thousandths of a millimeter.

TABLE I.

Current.	Deflection.
14	0.0
46	1.7
85	6.7
123	16.7
155	29.2
195	45.9
246	80 8
300	130.1
367	200 0
431	272.8
473	297.0
502	330.0
604	335.0

We did not carry the increase of current to a higher value, since the deflection of the diaphragm would have become so great as to carry the style out of the field of view.

A comparison of these results — best seen by plotting them as a curve, which we have not thought it necessary to reproduce here — shows that on increasing the magnetizing current the corresponding permanent deflection increases more and more rapidly in proportion up to a value of about $\frac{8}{10}$ of an ampere, after which the deflection is very closely proportional to the current.

In studying the effect of different degrees of magnetization of the core of the receiver upon the amplitude of the vibration of the diaphragm, our mode of procedure was to pass a known direct current through the magnetizing coil, and to vary the alternating line current through the receiving telephone coil, measuring this current by the electro-dynamometer. The extent of the excursion of the diaphragm for each different current was measured by the spider-line micrometer. The deflections given in the tables are each the mean of five readings. The process described was followed for various values

of the magnetizing current, with the results shown in Table II. The figures in the first vertical column indicate the serial number of the measurements; those in the second, the strength of the magnetizing current in milliamperes, to which the strength of the magnet was found to be proportional; the figures in the upper line headed L, the various values of the alternating line current in milliamperes; and the figures in the columns vertically beneath these last, the corresponding amplitude of vibration of the diaphragm in thousandths of a millimeter.

TABLE II.

No.	M.	L.			
		5.0	12.5	21.0	29.5
1	77	4	7	10	14
2	123	8	14	21	27
3	180	12	23	34	43
4	235	17	28	39	47
5	287	23	47	63	81
6	322	37	76	102	127
7	352	44	86	106	130
8	376	31	71	100	120
9	394	26	68	88	113
10	416	30	60	87	107
11	459	22	40	56	69
12	503	16	30	39	50
13	564	8	17	28	36
14	639	8	12	16	21

The results of a portion of the measurements are shown graphically by the curves in Figure 1. Only series 1, 3, 5, 6, 7, 11, 13, 14, are reproduced, as a greater number would have been likely to render the diagram confused. The abscissas are excursions of the diaphragm in thousandths of a millimeter; the ordinates, the line currents in milliamperes. The several curves are numbered to correspond with the serial numbers in the table.

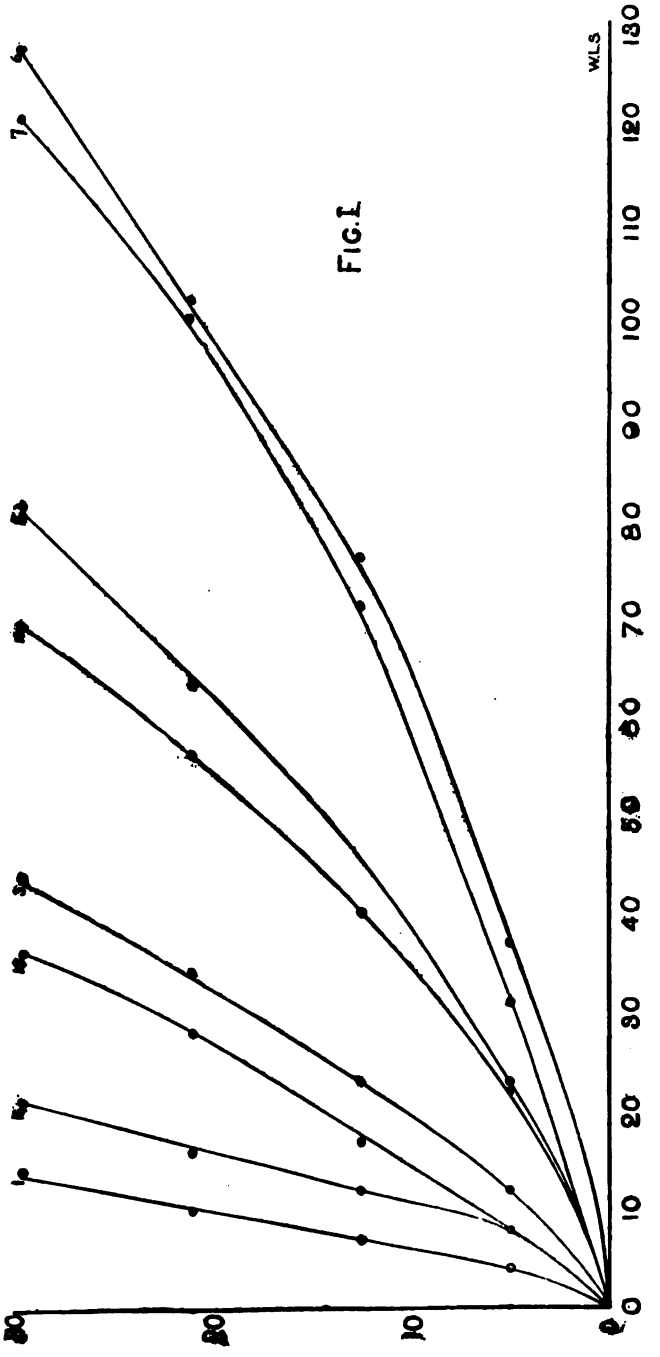

FIG. 1.

It will be seen from these results that, as the strength of the magnet of the telephone increases, the amplitude of the vibration likewise increases up to a certain limit and then falls off. A comparison of them with a curve representing the magnetization of the magnet as determined by means of a ballistic galvanometer showed that the maximum motion of the diaphragm with a given value of the alternating line current is reached before the core reaches half saturation.

An inspection of the curves also makes it plain that in general the amplitude of vibration of the diaphragm increases less rapidly than the current actuating the telephone.

In the experiments previously described the strength of the magnet was kept constant in each series, and the line current was varied. A series of measurements was also made in which the strength of the line current was kept constant, while the strength of the magnetizing current was varied, which shows very clearly the manner in which the amplitude of vibration changes with change in the strength of the magnet. Table III gives the results obtained. The currents and amplitudes are given in terms of the same units as heretofore.

TABLE III.

Current.	Amplitude.
35	5.5
76	13.6
149	20.5
208	42.3
256	60.8
273	66.0
302	84.5
321	106.5
352	111.5
378	99.8
398	89.6
480	45.4
560	28.0
671	11.6
780	8.5
984	4.0
1,142	3.0

Beyond the highest value given in the table, 1,142 milliamperes, the excursion seemed to remain almost constant and of too small a magnitude to be measured readily.

Figure 2 illustrates graphically the results obtained. The amplitudes of vibration are represented by the ordinates of this curve, while the abscissas represent, in terms of an arbitrary unit, the strength of the field at the diaphragm, as obtained from the previously constructed curve of magnetization already referred to.

The figures obtained in these measurements lead to precisely the

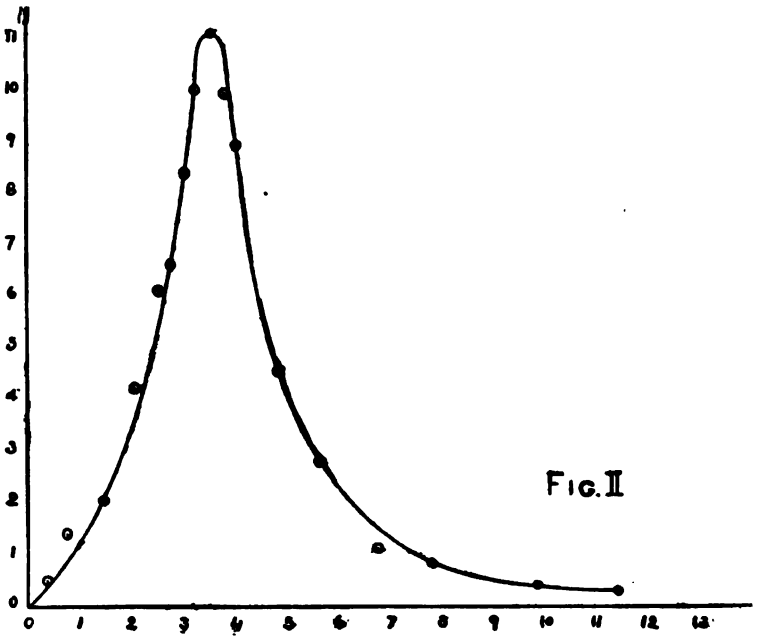

FIG. II

same conclusion as those already discussed, showing that the amplitude of the vibration of the diaphragm produced by an alternating line current of a given strength increases up to a certain point, and then decreases to a very low value. The point of maximum amplitude is far below the saturation limit of the magnet. It is evident, then, that it is not desirable to use an excessively strong magnet with a magneto-telephone receiver — a result which agrees with the conclusions set forth in both of the papers cited at the beginning of the present article.

Our observations were not made with the direct intention of deter-

mining the absolute magnitude of the excursion of the telephone diaphragm, but they may throw some light upon the subject regarding which the figures given by different observers differ widely. Dr. C. J. Blake,[1] by inscribing the vibration on a plate of smoked glass, obtained a value of 0.02 mm., and by the use of a micrometer screw with galvanic contact a value of 0.0135 mm. Salet[2] employed an optical method similar to that employed by Fizeau for measuring the expansion of solids, based upon the variation in position of Newton's rings when these were formed between a light piece of glass carried by the telephone disk and a fixed disk of the same material placed in front of it. The excursion as thus measured was from 0.0002 mm. to 0.0003 mm. Fröhlich[3] measured the excursion by means of a beam of light reflected from a mirror carried by the diaphragm, the beam being cast upon a screen and its motion measured when the receiver was operated. He gives 0.035 mm. as the value of the amplitude of the motion of the diaphragm. Franke[4] employed an optical method similar to that used by Salet, making the assumption that the amplitude of the vibration is proportional to the strength of the current — a supposition, however, which our own results, as given in the preceding pages, do not fully bear out; he concludes that the excursion of the diaphragm for a sound which is just audible is less than 1.2×10^{-6} mm.

Some of these differences are doubtless due to the different transmitters used. Blake employed a box magneto-transmitter, Salet a hand magneto, and Fröhlich a microphone. Also it is very possible that in some of the methods there is more or less interference with the free motion of the diaphragm. The following considerations may therefore be of interest, although they do not lead to absolutely conclusive results.

In all of our experiments the line current had a value considerably in excess of even a strong telephone current. The weakest value of the line current employed was five milliamperes, while even two milliamperes is a large value for a telephone current produced by a powerful Hunning microphone transmitter. Hence the actual values of the

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[1] Journal of the Society of Telegraph Engineers, 1878, 8, 178.

[2] Comptes Rendus, 1882, 95, 178.

[3] La Lumière Electrique, 1887, 25, 180.

[4] Elektrotechnische Zeitschrift, 1890, 11, 288.

excursions measured by us are much larger than those assumed by the diaphragm of the telephone receiver in practice. We have, however, endeavored to calculate this approximately from the data at hand. It is clear that, if we can obtain the equation of one of the curves in Figure 1, which corresponds to a strength of field of the magnitude employed in the ordinary telephone receiver, we may from this obtain the desired result by substituting in this equation the value of the telephone current. A study of the curves shows that they are all approximately parabolas with the equation $y^2 = mx^n$, n being greater than 2, but the values of m and n are different for the different curves. It was necessary, therefore, to determine by experiment the strength of the field actually employed in the magneto-receiver. This was done in the following manner. A magneto hand telephone was so placed that it produced a deflection of 45° in the needle of a delicate magnetometer. The telephone was then replaced by the magnet and magnetizing coil used in our experimental apparatus, and the current through the coil was varied until a deflection of 45° was produced in the needle. The current producing this effect was found to be 52 milliamperes. A like experiment being performed with a second telephone, the value of 62 milliamperes was obtained for the magnetizing current. The latter value was chosen as it came nearest to a strength of current which we had actually used, viz., 77 milliamperes, the lowest magnetizing current that we had employed.

By the use of the logarithmic method the equation of this curve was found to be $y^2 = 0.305\ x^{3.26}$, in which y represents the current and x the corresponding amplitude of vibration. Substituting in this equation the value of 2 milliamperes for y, this being the value of a strong telephone current, we obtain the corresponding value of x, which is 2.2; that is, the excursion of the diaphragm of a telephone receiver with the strength of field corresponding to the curve would be 22 ten-thousandths of a millimeter. But the true excursion is probably somewhat less than this, since the strength of field for which the equation holds is somewhat greater than that employed in the telephone, and for a magnetization of this value the deflection would be larger with the stronger field.

It may also be inferred from the preceding results, that so far as sensitiveness is concerned it would be advantageous to employ a stronger magnet in the receiver than is at present used. With the modern microphone transmitter this is not necessary, and upon lines

where there is much disturbance it would be harmful, as the proper procedure in such cases is to strengthen the transmitter as much as possible, in which case the receiver may be less sensitive. But if a less strong transmitter is used, as, for example, a magneto-telephone, and upon lines free from disturbance, increased sensitiveness in the receiver is very desirable.

ROGERS LABORATORY OF PHYSICS
May, 1892.

BACCALAUREATE SERMON.

By REV. E. WINCHESTER DONALD, D.D.

Trinity Church, Boston, May 28, 1893.

And King Solomon sent and fetched Hiram out of Tyre. He was a widow's son of the tribe of Naphtali, and his father was a man of Tyre, a worker in brass. And he was filled with wisdom and understanding and cunning to work all works in brass. And he came to King Solomon and wrought all his work. — *1 Kings vii: 13, 14.*

King Solomon is invariably represented as preëminently wise, and he never showed his wisdom more conspicuously than in his choice of a man technically skilled in the department of metal working to execute, and very likely to make, the plans of those parts of the Great Temple which required a union of strength and beauty. Hiram was selected because he knew how to do what he was asked to do, and for no other reason. He obtained his commission on his merits. His views of the sort of ritual the Temple Service was to illustrate, his opinions of the Ecclesiastical Canons which were to govern the official conduct of the priests, were not inquired into by the wise king. It was his competence to take charge of a most important branch of the splendid architectural undertaking which alone led Solomon to send down to Tyre a formal invitation to become chief engineer and architect of the famous structure. Like all too many men who have served their fellows faithfully and skillfully in the field of mechanical art, we know nothing of him save that he did his work well. Nothing better, however, could be known of any man.

The story is a picturesque and interesting illustration of the possibility of an intelligent and cordial union of the men of mechanical art with the men of institutional religion. Their real interests are one, and each is incomplete without the other. The Temple was no more Solomon's than Hiram's; Hiram's no more than Solomon's. Solomon furnished an idea; Hiram built a house for the idea. Which was the greater achievement let some one else debate and decide. At any rate, so exactly and splendidly did the great building express the superb idea of national unity and national worship, that when the idea became vague, became endangered by strife,

formalism, idolatry, and a spurious spirituality, there stood the great building lifting its huge bulk and glowing beauty against the sky, irrefragable testimony to the worth and blessing of loyal devotion to the God of righteousness, truth, and justice. Hiram's work saved Solomon's idea in more than one crisis of Israel's history.

But the cordial union of the men of mechanical art with the men of institutional religion in a visible, particular undertaking, is really an exhibition of the principle of essential interdependence which runs through all life to give it substance and unity. The claim of any science or of any profession to a rightful domination over every other is thoroughly irrational. A church regnant, or a university regnant, would mean inevitably disturbance and loss in the life of mankind or nation. Primacy in all things is safely placed in the hands of no man, nor in the custody of any body of men representing a single department of human activity, knowledge, skill, or purpose. Civilization is as safe in the hands of chemists as in the hands of priests, and no safer. Civilization is at its best when it is the outcome of the sympathetic, intelligent, reasoned union of all human forces. Distrust, depreciation, denunciation, from whatever quarter they come, are marks of a disturbance of the normal relations of one activity and its achievements to another activity and its achievements. The cry for the reconciliation of religion and science is a stupid cry, and has recently become irritating to our ears; but the wish for the cordial agreement and intelligent coöperation of religious men and scientific men is one of the most acute of our time, and one which there are reasons for believing may one day be realized. But it will be fulfilled, not by a similarity of methods, not by identity of pursuits, still less by successful attempts to subordinate religion to science or science to religion; it will be most finely and lastingly fulfilled by the universal recognition that the establishment of any fact and the verification of any truth, the discovery of any laws and the mastery of any force, are equally contributions to the discipline and development of human life, and are equally necessary to the final completion of human life upon our globe.

And I like to think that the circumstance which has brought us together this afternoon is indicative of the existence of a belief among you that what science stands for and what religion represents belong to one another. The work of Trinity Church and the

work of the Massachusetts Institute of Technology are not hostile or alien to one another, however variant be their methods and the material with which each has to do; rather are they allies rendering to man different but equally imperative services, and rightly expectant of man's gratitude and support because of the intrinsically valuable nature of the service rendered. You asked the use of this church and the voice of its minister because you wished, before going out into the untried future, to implore the blessing of God upon yourselves and upon the tasks which years of toil and training have fitted you to perform; and you are the more ready to ask for that blessing because of your deep, intelligent conviction that these tasks, and the skill you have patiently acquired for meeting them, may rightfully claim the help of God. The church joyously, proudly, hopefully receives you because it recognizes the incalculable value to the world of your special knowledge and ingenuity, hailing you as the latest addition to the ranks of those who are making the world a better place in which to live and work.

It is this joint act of ours which I wish to emphasize, for, unhappily, an impression is widely prevalent that there is an inherent antagonism between the men who study material forces and the men who study spiritual forces. But that impression is totally unwarranted, for, in the first place, the natures of the men who have thrown their force into the different fields of human enterprise are identical. They are moved by the same elemental conceptions of what it is to be a man and of what being a man involves. The supremacy of conscience, the absolutely imperative claims of truth, the call of purity and honor and compassion, and the awful mystery of life and death, press equally upon us all. They are the inexorable conditions under which all men do any sort of work, the common meeting ground on which every one of us must stand to receive his orders, to be shown his duties, and be girded with the strength without which each of us cannot but fail and finally fall.

It is simply turning the world upside down to suppose that there is any imaginable legitimate field of human activity from which the great primary, elemental imperatives of life can be driven. The strain upon the conscience is the same for electrician and poet; the behests of truth confront the chemist and the priest; and the sense of the sacredness of human life moves the bridge-builder and the judge; for, apart from anything a man may have set himself to

do — nay, rather, in everything a man shall undertake — there is forever and forever the abiding question of what the man himself becomes. It cannot be eliminated. His beliefs may change, his habits alter, his aims mount higher or sink lower; no matter; he is forced to pass judgment upon himself more frequently than upon what he achieves. Sooner or later the fact that he is a man is seen to be more important than the special occupation which has absorbed his personal force. "What are you, O man, who have given the strength of your clever brain and the endurance of your body to the discovery and mastery of material and force? What are you, O priest, who have moved for years through your round of services? who have thought of love and law, of sin and holiness, of repentance and faith all your days. What of yourselves, as you stand among your achievements and count up your gains and losses?" Scientist, poet, priest, or citizen — you know that you must tell yourself what you have become, what you have helped other men to be. Here in the beautiful presence of God's House does it not become instantly and lucidly clear that identity of natures, not diversity of pursuits, determines whether there can be any inherent antagonism between the men who stand for science and the men who stand for spiritual forces in the world? If there haunts the mind of any of you to-day the suspicion or the wonder whether, in the new life to which this week you go, there are circumstances or conditions inherent in your training and in the pursuits for which that training has fitted you, which must separate you from the life of God and free you from the duty of obeying His laws, put it away from you as both irrational and unworthy of the nature you proudly bear. Make personal this corporate act of worship, and let it stand henceforth forever in your memory as the moment when you acknowledged that whatever you should be called to do you were to do it as the servant of God.

But more than this must be said. In one most splendid feature of endeavor the work of the man of mechanical art illustrates the inexorable necessity of truth. It is his function to discover what *is;* to wrest from ignorance knowledge of the properties of matter; to explore the subtle play of forces; to separate, combine, apply, transmit, transmute, regulate, and master them to secure special results. It is an absolute condition of such work that the worker must be unremitting in his fidelity to what really is. Every appar-

ent gain must be subjected to a pitiless test. Guesswork is ruled out if it cannot be reduced to certainty. A perhaps may produce an explosion; a peradventure negative the most brilliant theoretical result. Everywhere the cry is for a demonstration supported by indubitable tests. As a consequence there grows up the stern conviction that nothing but truth can live; that no falsehood is for a moment safe in the presence of innumerable and pitilessly stern tests, which sit as incorruptible judges in the supreme court of fact. There are no finer pages in our history than those which tell the story of the great men of science who have hastened to publish their mistakes when larger knowledge has convinced them of their mistakenness, who have gladly abandoned the very theories which gave them their fame when, by their own discoveries, they have been the first to learn that those theories were untenable. Without waiting for detection they have confessed error. Beyond all the contributions which men of science have made to the comfort, the glory, the expansion of our civilization stands this: that they have taught the world that nothing lasts save truth; that no theory and no plan which is not the legitimate child of truth and fact can ever be a permanent addition to the possessions of mankind. Literally a false weight is an abomination to the scientific man. He hates with an intelligent and scornful hatred everything which is something other than it pretends to be, because he is safe only with what is what it can be verified to be. He knows that for him to put the unreal for the real, the flimsy for the strong, the false for the true, in any least process or product of his art, is to destroy his work and to discredit himself. It is as if one should surreptitiously slip a false scale upon the draughtsman's table or a light weight into the chemist's rack. But is there anything which should so firmly link the man of science to the man of religion as love of truth, however fine they make the distinction between truth and accuracy? Fundamentally they are the same. And it is love of the truth in one field of endeavor which fits a man to love it everywhere. Right here, then, is a chance for the men of science and the men of religion cordially to clasp hands, recognizing that each is in search of truth, each anxious to display the value and necessity of truth, each determined that nothing shall pass unquestioned, whether it be the strength of a beam of steel, the purity of an acid, or the moral quality of an act, each

eager that only what is rooted in fact shall claim man's acceptance. Surely it will be the most natural of all natural acts that each should find in the other's work the complement of his own. How grateful should the man of religion be to the man of science for every discovery made in nature when that discovery is amply verified, for all thoroughly ascertained knowledge of how the world came to be, for every disclosure of the laws by which a wise God governs his universe! How grateful, too, should be the man of science to the man of religion for every demonstration of the value of holiness, the power of worship, the dreadfulness of spiritual disobedience, and the realized, evident, measured power of prayer in the domain of the spirit! The distrust of our scientific Ephraim would disappear, and the depreciation of our religious Judah vanish away in this chivalrous and cordial appreciation of the essential kinship of each other's work.

For too long — far too long — have men ignored the existence of the bond that binds all lovers of the truth together. For too long have they been marshaled in hostile armies and embittered by unreasonable strife. Is it too much to hope that the coming years are to be made lustrous by a new perception of the spiritual kinship of all men who are searching for truth in any field where it may be found, of the absolute spiritual identity of all results which rest upon what man can verify to the intellect, the conscience, the soul, of the race?

And yet once more: there is an identity of purpose which keeps the man of science and the man of religion at their work. That purpose is the service of our fellows. Sooner or later the results of all true endeavor become the common possession of mankind. Men who never heard of Plato use the Grecian's arguments when they talk politics, and are moved by his ideas when they dream of a social heaven on earth. There is no conception of truth too lofty to be translated into the vernacular of the multitude. In the universities have been born nearly all the great movements of modern times, however difficult it be to track them back to their source. And no brilliant discovery has ever been made by astronomer, chemist, geologist, electrician, mineralogist, or engineer that has not finally been turned to account in the utilities or adornments of life, or does not hold the promise of it before our eyes. The generous support which the public gives to all its schools of technical

art is the public's testimony to its faith in their value as contributors to the public stock. Every man who is discovering *what is*, but has been concealed, is serving his fellows. Every man who is finding new uses for old material is adding to the common capital. Every man who is eliciting and applying force is increasing the general power.

To furnish humanity with new tools wherewith to work richer results; to remove every obstacle to the freest play of all man's powers; to lessen danger and wear and waste; to increase safety and health and skill; to give ignorance and weakness a chance; to make everything that is helpful and pleasant plentiful — that is the purpose of those who are imagining and executing the astonishing things which signalize our day. I will not believe, on any evidence thus far offered, that the motive of our modern energy in the realm of physical science is a sordid eagerness for gain or a vulgar craving. for fame. The man who discovers a new use for common material or a new application of an already measured force should be the man who feels the thrill of happiness of him who can stop the throbbing of a nerve or clear the perplexity of a bewildered brain; and more often than much shallow and foolish talk would lead us to believe, he is that man. The comforts and conveniences of life which strip toil of its harshness and multiply our personal force may be the instruments of spiritual culture, as, indeed, thousands are ready to testify they have found them to be. It ought to be so clear that no one need miss it that the men who bridge the stream and plan the house, who mine the coal and forge the steel, who compel the electrical force to turn a wheel or to blaze in light or to weld iron bars, are the servants of the people, and are furnishing them with the conditions under which fullest vitality is possible. And what said Jesus to his friends when they were debating the question of superiority among themselves? Who is greatest in the kingdom of heaven? The man who serves. He who gives a cup of cold water only shall not lose his reward. But what of him who brings down from its home among the beautiful hills, before subtle poisons have mingled with its limpid streams, the crystal water into every home of the city with a baptism of cleanliness and health — shall he lose his reward? He truly served his fellows and takes his place in the ranks with all who have made the life of man richer, fuller, stronger, whether by science

or by religion. He has been obedient to the great law of service as truly as were Luther and Wesley, Hampden and Lincoln, Raphael and Beethoven, Shakespeare and Browning, Savonarola and Phillips Brooks. Just as truth unites by a real instead of an artificial bond all lovers of the truth, so does obedience to the law of service make brothers of those who serve, whatever be the sort of service given. And when, as is always possible, they who have set themselves in any field to the cultivation of any fruit for the refreshment and sustenance of their fellows shall see that in Jesus Christ what man should be, nay, what man may become, is the noblest vision of the perfect man, then each of us shall be most profoundly moved to give our service from a motive so high and pure and lasting that the Republic, Utopia, the Kingdom of Heaven — call it which you will — shall be established on this earth, prepared to receive the New Jerusalem, the city of God, which hangs in the heavens over us ready to descend when the earth and man are fitted for its coming.

Gentlemen of the senior class, you stand to-day on the summit of the privilege of your years of discipline and training. You look back with gratitude, tinged with regret, perhaps, for days when faithfulness slackened; with a quickened throb of the heart that close ties and happy friendships are no longer to be strengthened and fed by daily companionships. But you look far down into the future that is beckoning you with its glowing hands. It is all bright with expectation and illimitable hopefulness. It ought to be. No one who has been young and still keeps his sympathy with youth would have it otherwise. Pausing for one quiet moment here in the quiet church you have heard of the essential nature of the work you are going to do. We send you out as searchers for truth and servants of men, who in that search and service are, by obedience to the law and love of God, to become yourselves the splendid illustrations of the power of truth, the nobility of service. The world wants you for the same reason that it wants the ministers and lawyers and doctors who shall be graduated next month across the Charles. It is counting upon you. It has been waiting for and calling you. And now you are ready. May God's blessing ever be with you, keeping your love of truth pure, your service noble. Accept the terms which truth and service offer you, "then burn to the socket!"

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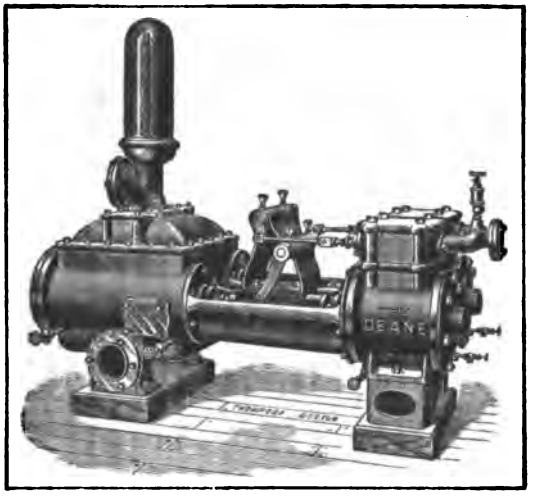

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Vol. VI. JULY, 1893. No. 2.

TECHNOLOGY QUARTERLY AND PROCEEDINGS OF THE SOCIETY OF ARTS

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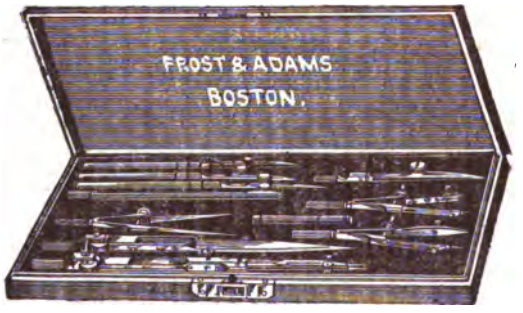

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PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. VI. JULY, 1893. No. 2.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FIRST YEAR, 1892-93.

THURSDAY, April 13, 1893.

THE 445th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Mr. George W. Blodgett in the chair.

The records of the previous meeting were read and approved. Mr. David J. Cartwright, of Boston, was duly elected an Associate Member of the Society. The Chairman then introduced Captain William Brophy, of Boston, who read a paper on the "Fire Hazards of Electricity." At its close the Chairman introduced Mr. H. S. Parshall, of the General Electric Co., who read a short paper on the same subject from the point of view of the producer of electricity. The papers are published in the present number of the *Quarterly*. An interesting discussion followed, after which the thanks of the Society were extended to Captain Brophy and Mr. Parshall, and the meeting adjourned.

THURSDAY, April 27, 1893.

The 446th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M.

The records of the previous meeting were read and approved.

The President was authorized to appoint a committee of five to nominate officers for the ensuing year. Prof. C. R. Cross, of the Insti-

tute, then gave an "Account of Some Recent Investigations in Acoustics Made in the Rogers Library of Physics." At its close the meeting adjourned.

THURSDAY, May 11, 1893.

The 447th and annual meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Mr. Henry M. Howe in the chair.

The records of the previous meeting were read and approved. The Nominating Committee reported for reëlection the names of the officers of the past year, and they were duly chosen for the ensuing year.

The reports of the Executive Committee and of the Permanent Meteorological Committee were read, accepted, and ordered to be placed upon the records. Mr. Desmond Fitzgerald, of Boston, was duly elected an Associate Member of the Society. The following papers were read by title:

"Electrolytic Reduction of Nitrobenzene in Sulphuric Acid Solution," by Arthur A. Noyes and Arthur A. Clement.

"Influence of the Introduction of a Sulphonic Group upon the Power of a Developer," by A. A. Noyes and W. K. Gaylord.

"Additional Notes on the Prismatic Stadia Telescope," by Robert H. Richards.

An amendment to Paragraph 4 of Section VI of the By-Laws was presented and laid over to the next meeting.

The Chairman then introduced Mr. Walter B. Snow, of the B. F. Sturtevant Co., who read a paper on the "Blower System of Heating and Ventilation." The paper is published in the present number of the *Quarterly*. At its close the Chairman expressed the thanks of the Society to Mr. Snow, and after some discussion declared the meeting adjourned.

CLEMENT W. ANDREWS, *Secretary.*

THE FIRE HAZARDS OF ELECTRICITY.

By WILLIAM BROPHY.

Read April 13, 1893.

In the following short paper on the "Fire Hazards of Electricity" I have attempted to present the insurance side of the question in as brief a manner as possible, as I understand the matter is to be fully discussed by gentlemen who, I have no doubt, will deal with this subject in a manner befitting its great importance.

On the introduction of the electric telegraph as a means of communication between distant points, the few wires stretched from pole to pole were not looked upon as a means of increasing the fire hazard, as their number was so few as not to be a serious hindrance to the fire department and the cases where atmospheric electricity followed the wires to the switchboard and instruments, causing small fires, were so rare as to hardly attract attention. By slow degrees, as the benefits of this great invention began to be appreciated, the wires began to increase; still, while they proved a hindrance, they were not looked on as a hazard to be seriously considered.

Later came the dial telegraph for communicating between local points and the stock ticker for sending out market quotations, but these increased the number of wires only slightly.

But after the invention of the speaking telephone and the perfection of the exchange system, then the increase of aërial wires was enormous; every available spot on roof or front of buildings was eagerly seized on by the busy linemen, often without due regard to the rights of owners or occupants. Lines of poles sprang up at all points, sometimes during the hours of night, and met the astonished gaze of the law-abiding citizens for the first time as they wended their way to their places of business. The location of these intruders was not always selected with a view to the comfort or convenience of these same good people, and often their protests were met by that trite saying, "Well, what are you going to do about it?"

With this enormous increase of electric wires the delays to the fire department became more frequent, and losses by fire were often greater than need be due to this cause; yet they did not endanger the lives of the firemen to any great extent, and were handled without fear.

Later came that new form of electric energy, the electric arc light. Gradually it worked its way into public favor, and gradually its power for mischief to the fire underwriters and owners of property became manifest by reaching the pockets of both. This was inevitable, owing to the first crude methods resorted to for the transmission of this new form of energy. The existing forms of insulation were not equal to the task of confining this greatly increased force within bounds, and, in fact, no other people in the world but our own would have permitted the introduction of an element fraught with such possibilities of danger to life and property with no real means for keeping it under control. But we are ever ready to take chances and assume risks in order to gain time or secure some improvement that will contribute to our comfort or add to our wealth.

With the introduction of this class of wires came another obstruction to the efforts of the firemen in extinguishing and preventing the spread of fires, and also a certain amount of demoralization in their ranks. Men who would face the flames, inhale poisonous gases, and stand beneath tottering walls without flinching, stood in wholesome dread of the arc-light wires. The former elements of danger they were familiar with, and could to some extent avoid, while the latter contained hidden, and to them mysterious, dangers that they knew very little of. To handle such wires or to come in contact with them meant injury or death. In addition to this they soon learned that the wires they had been accustomed to handle with impunity, and remove when an obstruction, were liable to become dangerous also; and, as a matter of fact, firemen are justified in refusing to handle electric wires in towns or cities where an arc-light plant is installed, unless during the hours when it is not in operation.

Next in order came the incandescent electric light, direct or low tension system. While the wires for this system proved another obstruction, they were not dangerous to life or limb; yet firemen, who are not expert electricians, looked upon them with mistrust. Later still came the electric power circuits. At first no greater than the usual 110-volt current was used, which is not dangerous to life or

limb. Later this was increased to 220 in order to reduce the cost of conducting wire.

Next came the transformer system of electric lighting, where a current of 1,000 to 2,000 volts is used in the primary conductors from dynamo to transformers. These were another obstruction and dangerous to person.

About the same time came the electric street railroads, with their trolley wires, feeders, span and guard wires. That these prove a serious obstruction at fires no sane man can deny. They also are a source of danger to the firemen, and contact with them is studiously avoided by those brave guardians of our lives and properties.

I have thus far dealt with but one feature of the fire hazards due to overhead electric wires. I now come to another — their liability to become the direct cause of fires.

First, is the liability to cause fires on the outside of buildings. Occurrences of this kind are rare, yet cases are not unknown. This is due in most instances to defective insulation at one or more points of the circuit permitting a derived circuit through or on the surface of inflammable material, and imperfect contact at binding posts and cut-out switches.

Next, we come to the greatest fire hazard from the overhead wires — the danger of electrical contact between the harmless low tension and the dangerous electric light and power wires. The arc, incandescent, power, railway, and alternating wires are capable of doing great damage in this way by sending currents greatly in excess of the safe carrying capacity of the smaller wires, and heating them sufficiently to cause the ignition of any inflammable substance in the immediate vicinity.

I will now consider the wires in the interior of buildings as a fire hazard, and will begin with those of the arc-lighting system. For the sake of securing sufficient mechanical strength, the size of wire used for this system has a much greater amount of conductivity than is necessary for safely conducting the current, so that no danger need be apprehended from overheating them. Where an abnormal amount of heat is produced in one of these circuits it is due to imperfect joints or connections, thus introducing an excessive amount of resistance at such points. There is also more or less danger from the arc lamp, due to broken globes permitting pieces of hot carbon to drop on inflammable goods, and also from improperly trimmed lamps, which

permit the burning out first of the carbons and then of the metal holders. This latter will surely cause trouble in many places.

Fortunately those engaged in the business of electric lighting recognize the wisdom of the practice of not concealing from view this class of wires, thus rendering the task of installing them with a reasonable amount of safety comparatively easy, and rendering their inspection less difficult.

Fire hazards from the incandescent system are confined wholly to the wires or conductors. The danger from the lamp need not be considered, though trouble can and does arise at times from the lamp socket. In a direct system, circuits, mains, and branches are supplied from a central station from one or more dynamos delivering current into one common conductor and thence through a system of feeders to the distributing mains. The electro-motive force necessary for the distribution of current in this system is not sufficient to cause serious injury by reason of shock to the nervous system, as it does not exceed 220 or 230 volts at the dynamo. But the quantity of current is sufficient to seriously burn a person under some circumstances, and would also under favorable circumstances cause serious loss by fire. The amount of current flowing from the generating station is limited only by the capacity of the dynamos and the number of lamps in use. The potential or pressure is as nearly constant as is possible to make it, but the amount of current is in proportion to the number of lamps. Whence, may be asked, comes the fire hazard from this system? A very natural question, and one that suggests itself to a great many people. But the fire hazard can be much greater from this than from the arc system. Hundreds of amperes of current are sent out over this system of feeders to supply lamps and motors, sufficient to melt down nearly if not all the interior wires in many buildings if, by reason of one of the many causes that suggest themselves to those familiar with the subject, an abnormal flow of current takes place over them.

You may ask, how can this occur? Current flow is regulated by the electro-motive force or pressure and resistance, or, if you please, friction. To supply a given number of lamps, or given size of motor, a given size of wire is necessary. The filament in the lamp affords a path of very high resistance for the current. As they are connected up in multiple the greater the number of these paths and the less the total amount of resistance. If through ignorance or motives of econ-

omy the supply wire is too small, heat is generated in the wire; and if the number of lights is sufficiently in excess of the safe carrying capacity of the wire, it can be brought to a white heat or even melted — a dangerous process near inflammable material.

If the wires are properly proportioned, and through any means those of opposite polarity (positive and negative) are brought into metallic contact, a path of low resistance is then established and an excessive flow of current results with the same consequences as before. Derived circuits established to and through the earth, caused by defective insulation, even though the points of contact be widely separated, will bring about this same result.

It is true that safety fuses are brought into play to prevent occurrences of this kind; but it is not an unusual thing to find fuse wires at the junction of circuits and branches far in excess in carrying capacity of the wires they are designed to protect, and it is not unusual after the fuse wire has performed its functions by melting to find it replaced by one whose fusing point is many times in excess of the original; and I have known cases where, after the failure of the largest fuse wire to maintain the continuity of the circuit, copper wire was substituted therefor.

The next hazard is from the fuse blocks or bases. The earlier types of these were of wood. Contact between wires and fuse being secured under screw heads, the inevitable shrinkage of the wood destroyed the contact, and heat, or a series arc was the first result, and later a fire, insignificant or of considerable magnitude according to circumstances. Too often these devices were concealed from view, thus increasing the hazard.

Next come the switches for turning on and cutting off this supply of current. When mounted on wooden bases they were capable of doing all the mischief ascribed to the wooden base cut-outs. In addition to this may be cited imperfect contacts, introducing an excessive amount of resistance and increasing the temperature to an unsafe point. The inexcusable practice of placing switches of insufficient capacity is sure to bring about the same results.

That undesirable trio, the combination fixtures for gas and electric lights, the cheap insulating joint, and wood or fiber base cut-out concealed under the metal canopy of the fixture, has been and is now another fruitful source of trouble and added fire hazard. The heat from the gas burners on a large fixture causes the fiber insulation to

shrink, permitting the gas to escape in small quantities at first, but steadily increasing in volume. The contact between screw head and fuse is destroyed from the same cause, a slight arc established, the escaping gas ignited, the fiber in the joint burned, and a burning gas flame limited only by the size of the pipe is the result.

Next in order comes that twin brother in iniquity of the swinging gas jet, the so-called flexible cord, to the ends of which are suspended so many incandescent lamps. The best of this is not safe in some locations, such as show windows or any other place where it is in close proximity to inflammable goods, while the cheaper grades are positively dangerous in nearly all places. While the use of this may be admissible for suspending lamps in the usual way in buildings which in themselves are of slow burning construction and contain little that is inflammable, the practice of fastening it to the walls or ceilings, either by means of cleats or staples, or concealing it between floors and partitions cannot be too severely condemned. Such a practice adds another to the fire hazards of electricity.

Next come the wires for incandescent electric lighting, their character, and the methods of installing them. It goes without saying that the very best of insulating covering is none too good for electric light wires. In many positions it should be water-proof, though there are cases where this is not necessary. Another desirable quality it should possess is non-inflammability, but very little of the best grades of insulation for wires possesses this desirable feature. Wires covered with any known grade of insulation, held in place by wooden cleats, add to the fire hazard to a greater or less degree, depending on their location, the distance between opposite poles, and the care with which they are placed in position. Wires that are concealed between floors, ceilings, and partitions, where not supported on non-inflammable insulators, and that are permitted to rest on gas, steam, water, or hot-air pipes, or other conductors, dependence being placed on the covering of the wire to prevent electrical contact, add to the fire hazard. Wires of opposite polarity run through a single hole in wooden joist, beam, stud, or partition, and laid side by side without a proper amount of separation, add to the fire hazard, due to the fact that the best form of insulation has a limited life, and to the other fact that the ever-present rodent finds some forms a dainty morsel. As a result of his feast an arc may be established, and if the insulation is highly inflammable a fire between the ceilings and partitions is rather apt

to follow. Loose connections and poorly made joints are another addition to the fire hazard. Joints when improperly made and not soldered soon become a source of danger. Solder alone will not insure a perfect joint and immunity from excessive heat at this point.

The practice of inclosing two wires of a circuit covered with a high grade of insulation in an insulating tube that is itself highly inflammable is another addition to the fire hazard.

All the causes assigned for increased fire hazard to this system of electric lighting apply to the system known as the alternating or transformer system, with the exception of the fact that the amount of current it is possible to convey into a building is limited to the capacity of the transformer. The lamps used on this system are usually what are known as fifty volts, and the current necessary to bring them to a state of incandescence is about one ampere. A 75 light transformer then could deliver only about 75 amperes.

I have endeavored as far as possible within the limits of this paper to give most of the causes for increased fire hazards due to electricity. It is due, however, to those engaged in the various branches of electric industries and those who use electrical energy for light, power, or the transmission of intelligence to state that many of the devices I have condemned are not now manufactured, although many are still in use, and that many of the bad practices that I have condemned are not indulged in by reputable men and firms.

I firmly believe that electricity in the service of man can be rendered docile and harmless, but to point out the manner in which this desirable end can be attained is beyond the scope of this paper and the limit of the time allotted to me at this meeting. This, however, might be made the subject of another paper.

I will now close by saying that the man or firm who will take advantage of the limited knowledge of electricity possessed by the average citizen and install electric wires in such a way as to increase the fire hazard should be deemed guilty of a misdemeanor, and, if fire results, should be deemed guilty of arson. The electric lighting company who would connect its service wires and furnish current to a building unsafely wired should be deemed an accessory before the fact, and punished accordingly.

It is within the power of those engaged in installing electric lights and wires and furnishing electricity for light and power to greatly reduce the fire hazard and stop the complaints of underwriters of the increased number of fires due to electricity.

FIRE RISKS AND ELECTRIC WIRES.

By H. F. PARSHALL.

Read April 13, 1893.

On the part of the General Electric Company I wish to state that its interests are not confined to any one system of transmission. It has extensive plants for the manufacture of cables of every description, *i.e.*, lead-covered cables, steel-armored cables, specially fitted for underground and submarine work; water-proof and rubber-covered cables, specially fitted for overhead work. It also has an extensive plant for the manufacture of underground tubes (as they are called), which have been extensively used by the Edison Company for a number of years, and have been found, without exception, satisfactory.

In order that it might most intelligently advise the public as to what system could be used with greater safety, the statistical department addressed a circular letter to the chief engineer of the fire departments of the principal cities in the United States of 20,000 inhabitants and upwards for information covering the following points for the municipal fiscal year most nearly conforming to the calendar year 1891:

Total number of fires from all causes.

Total damage caused by same.

Total number of these fires which may be attributed to electric lighting circuits.

Total damage caused by same.

Total number of fires attributed to electric circuits of every nature.

Total damage caused by same.

Out of 165 cities coming within the scope of this inquiry replies were received from 82. These replies were tabulated, and show that about 1.23 per cent. of all fires are caused by electric circuits, or about one fire in 75. Of these .13 of 1 per cent. were attributed to power circuits. The damage done by these fires was about 1.02 per cent. of

the total loss from fires — .78 per cent. from lighting circuits, .23 per cent. from power circuits. In other words, the loss due to electric circuits is about $1.02 out of each $100 due to all causes.

It appeared from the figures that Boston had been particularly unfortunate from fires caused by electric wires, some 2 per cent. of the alarms being caused thereby. It is to be noted, however, that one half of these alarms were caused by overheated thermostats and fires on street cars. The amount of damage done was uncertain, since it has been proved by some of the highest authorities that some of the large fires that were attributed to electricity were due to other causes. The loss in other large cities, however, was much smaller. In Philadelphia the number of alarms from electric circuits was only 0.7 per cent., and the loss therefrom was only 0.1 per cent. In St. Louis the number of alarms from electric wires was only 0.5 per cent., the loss therefrom only 0.04 per cent. It seems reasonable to suppose that a greater loss per fire in Boston might be due in a considerable measure to the narrowness of the streets and the greater difficulties in fighting conflagrations when under way.

Taking into consideration that most of the fires attributed to electric currents were on circuits that had been installed a number of years ago when the art of wiring had not attained its present perfection, it was not apparent that any decided recommendation could be made by the General Electric Company from the standpoint of fire risks. As, however, underground systems are not exposed to storms, and therefore offer a more reliable service, the underground system of tubing has been recommended for general use in low tension lighting systems.

From December 31, 1890, to January 31, 1892, there were 260 fire alarms here in Boston sent out, from careless use of lamps, candles, kerosene oil, and matches, as against twenty-six due to electric wires, most of those due to electric wires causing no loss.

With respect to internal wiring in general the following points are worth considering:

1. That a sufficient price shall be paid for all work done to insure reliable work and competent inspection.

2. That only those contractors shall be considered whose reputation is worth more than the profits on any particular installation.

3. That a liberal allowance of copper shall be made in all the mains, so that when an increased number of lamps shall be required

(as almost invariably happens) the mains first installed shall not be dangerously overloaded. As a practical example of this I have in mind a building the drop of which is now 20 per cent., which was originally thought to be amply wired. Such a state of affairs, I am led to believe, is not uncommon, and is neither economical from the standpoint of the investor nor safe from the standpoint of fire.

4. No electric wire should be run into any building without providing automatic cut-outs, so that if the current in that circuit exceeds its safe carrying capacity the circuit in the building will be automatically cut out. Telephone and telegraph wires have been strung indiscriminately, and many of them have afterwards been abandoned but not removed. These wires are small and easily deranged, and as no one has kept them repaired they are a considerable source of menace. Practically all of these abandoned wires are without safety devices for cutting them out of circuit, so that when one of these wires drops across a trolley line there is the greatest danger. Many of these wires were strung before high tension wires had to be considered, and are in places where there is the most imminent danger therefrom. No excuse exists for not putting safety devices on the circuits of all such wires since the currents normally carried thereby are exceedingly small and the increase of resistance by such devices is infinitesimal compared with the total resistance of the circuits. Further, if the safety devices are intelligently designed no interruption of service can be caused therefrom.

5. All low tension wires (*i. e.*, wires adapted to carry only small currents at low voltages, such as telephone, telegraph, messenger, and signal wires) should be placed underground. We have had sufficient experience with such to enable us to state that this can be safely and economically done. Aside from the increased fire risks caused by such wires being overhead, the numerous severe storms here in New England make the service of such an overhead system unreliable.

Having now safely disposed of all low tension wires the question arises what is to be done with the high tension wires? This problem does not admit of easy solution. It is obvious that with all low tension wires (which are generally uninsulated) underground, far less trouble is to be expected from high tension wires, since with the exception of the trolley wire these high tension wires are

generally thoroughly insulated and of such size that they are not easily deranged.

With respect to the feeders and mains of street railway systems it is to be borne in mind that these feeders and mains carry considerably more power and at higher tension than those of any other class of circuits. Hundreds of horse-power are, in fact, sometimes carried on a single large cable, so that in case of the short circuiting of one of these cables, even if under ground, considerable trouble might occur to any telephone or telegraph wires, water or gas pipes in the vicinity. Further, these mains are subject to greater fluctuation of service than any other class of mains, so that to have the same safe margin for the maximum current carried the cost of these mains would in many cases be prohibitive.

It may eventually be found practicable to put this class of wires under ground, but it should be understood that there are difficulties to be surmounted that do not exist with other classes of electric wires.

It is frequently stated as a possibility that the trolley wire can be safely put under ground. Experiments have been made costing hundreds of thousands of dollars, and none of them have indicated the practicability of doing this. The conditions in this country are not favorable for the construction of satisfactory conduits. This climate is so severe that the effective insulating of the contact wires from the earth is exceedingly difficult. The problem of making contact from the car with the underground wires is the one above all others in conduit work that is most difficult. The width of the wagon tires and sleigh runners in this country is such that only a very narrow slot is permissible, and to make a durable contact plow to run in the width of slot to-day permissible is out of the question. Contact plows of nearly every description have been devised, but not one of them has proved sufficiently successful to warrant recommendation for general use. Considering, however, that there are some 240 miles of exposed trolley wire in Boston, and that the loss by fire from power circuits in the period named above was only 0.01 per cent., also the statements made with respect to abandoned telephone and telegraph wires, it is evident the *trolley* wire does not perceptibly increase the number of fires.

With respect to guard wires that have been used over trolley wires: it is apparent that with other wires placed under ground

any theory regarding the usefulness of these guard wires would have to be abandoned. Even with the present state of affairs I believe these guard wires are of most doubtful advantage. They certainly contribute to make the present trolley system more unsightly than it would otherwise be.

It appears to the writer that the principal difficulties to be anticipated in power circuits are in connection with battling with fires. In general; while the voltage employed for railway circuits is such that there is no danger to life directly therefrom, the favorable opportunities for getting a shock in the vicinity of a fire to some extent embarrass and impede the action of the firemen, since when a fireman has received a shock he immediately lets go and is best satisfied not to repeat the experiment, as he is not convinced that he has received the full effect of the electro-motive force acting. To guard against occurrences of this sort, and at the same time avoid troublesome delays to passengers, emergency corps might be organized by the street railways with alarms operated by the city fire department, since by adopting this means there would be the least delay in getting these emergency corps in action; they should, in fact, if possible, be on the ground before the firemen. With emergency corps working with the same efficiency as the fire companies, and with a proper system of alarms, there should be no trouble to the firemen from electric wires, and the interruption of the traffic of the street railway companies would be minimized.

In conclusion, with respect to electric circuits, it should be said that the use of the electric light tends to greatly diminish the number of fires; that there is no other system for the transmission of great amounts of energy that is attended with so little danger; that the conveyance of energy by means of electricity has in general been found so simple that in many cases (in times past) the most ordinary precautions have been neglected; that the danger therefrom is small compared with any other means for conveying the same amount of energy; that even with the tremendous amount of energy so conveyed the danger has been rendered infinitesimal by competent supervision and improved apparatus; that low tension wires are to-day to be considered most dangerous from a standpoint of fire risks, and that the danger therefrom can be eliminated by reasonable means.

THE BLOWER SYSTEM OF HEATING AND VENTILATION.

By WALTER B. SNOW, S.B.

Read May 11, 1893.

From the open fire of the savage to the fireplace, the stove, the furnace, and the present perfected systems of steam, hot water and hot air heating, the art of heating has kept pace with increased human sensibilities and the desire for more refined methods.

In matters of ventilation, increased knowledge and personal demand have crystallized public opinion into statute laws looking to adequate methods for school, theater, hospital, church, and factory.

The earlier authorities based their calculations of necessary air-supply upon, and made it practically equal to, the actual volume expired from the lungs; just as though a person could inspire from one reservoir and expire into another. We now know that under ordinary conditions the vitiated air expired immediately and intimately mixes with the surrounding atmosphere, so that the question of ventilation becomes merely one of diluting a polluted atmosphere to such an extent as to confine its vitiation below some predetermined maximum.

Carbonic acid gas, of which we hear so much in its relation to ventilation, is not in itself a dangerous impurity when present in such proportion as we find it even in the worst ventilated rooms; but, fortunately, it is a direct measure of the character of the atmosphere with which it is associated, so that its presence as determined by simple methods is relatively indicative of the existing proportion of positively injurious vapors, gases, and suspended particles.

In the atmosphere of the open country there is present from 3 to 4 parts of carbonic acid gas in 10,000 parts of air, while in that of an inclosed apartment in which a musty odor is barely perceptible to one entering from out-of-doors there will be found not less than 6 or 7 parts in the above-named volume. Good ventilation, is measured by the presence of not more than 6 parts, and

fair ventilation by not more than 8 parts of carbonic acid gas in 10,000. It is readily deducible that, to maintain a proportion of 6 or 8 parts in an apartment continuously occupied by a given number of persons, 3,000 or 1,500 cubic feet of air will be required per hour per individual according to the proportion of carbonic acid.

An ordinary schoolroom, containing 56 pupils and teacher, would thus hourly require from 171,000 to 85,500 cubic feet — equivalent to passing through the room once in every 5 to 10 minutes a volume of air equal to its entire cubic contents.

The State Inspectors of Massachusetts require 30 cubic feet of air per pupil per minute for schoolhouse ventilation — not from hygienic deductions, but because it appears upon investigation to be the practical limit attained by existing methods in this Commonwealth.

Their original attempt to secure 50 cubic feet of air per head per minute would have resulted in remodeling, with scarcely an exception, every school building in the State. *Financial* outweighed hygienic influences, and the limit was dropped to 30 cubic feet.

Almost all existing systems, particularly those installed prior to the last decade, depend for the necessary air movement either upon the natural action of vent flues and foul air shafts or upon their increased efficiency due to heated stacks or steam coils. All such methods are, however, largely at the mercy of climatic conditions. As the external temperature rises they must of necessity become less effective; heavy winds will ofttimes reverse their action, and damp and muggy days are noticeable in their effects. They are unstable, untrustworthy.

Some means, always positive, always reliable, must be adopted. Nothing short of a positive acting mechanical device is capable of accomplishing the desired results. The fan-blower stands preëminent as most economical of power for air volume moved, as most easily applied, and most readily operated.

The past ten years have witnessed the rapid introduction of the fan, not only as an adjunct to old systems of ventilation and heating, but more prominently as the primary feature of a newly developed method of hot air heating. The blower system of heating and ventilation as herein described comprehends only that method by which ventilation is secured under plenum conditions, that is,

when the air is forced into rather than exhausted from the building, and comprises in its completeness a steam-heater or heaters, a fan, driven by some type of motor, and a system of ducts and flues through which the air is forced to the various apartments of the building.

Although the State law now requires adequate ventilation in factory buildings, yet it must be admitted that in the introduction of the blower system the owner's first motive is usually mercenary rather than humanitarian. But the blower system fortunately possesses this particular feature, considered solely as a heating system, namely, that in order to heat successfully it is necessary to supply a volume of air sufficient at the same time to thoroughly ventilate any ordinary factory structure where the processes are no more than ordinarily objectionable.

The introduction of the blower system is, therefore, divided between two great classes of buildings.

First, where heating is preëminent and ventilation is merely incidental, and —

Second, where the system of ventilation is of primary importance, and heating is necessarily combined with it for successful operation rather than introduced as an independent system.

To the first class belong almost exclusively all manufacturing buildings, storehouses, drying-rooms, exposition buildings, and some offices and stores.

In the second class are those buildings in which specially objectionable processes are carried on — hospitals and asylums, all halls of audience (including theaters, churches, and schools) — and stores and offices not included in the first class.

The enterprising manufacturer is quick to appreciate his financial interest in the provision and maintenance of an atmosphere in his factory that exhilarates rather than wearies his employees; for a direct monetary return can be shown in the improvement in quantity and quality of work resulting from the introduction of the blower system with pure air and a comfortable temperature.

The blower system has met with special approval at the hands of the manufacturer on account of the utilization of his exhaust steam without imposing unnecessary back pressure on his engine. Doubtless one great element in its success in the mill and factory has been the usually excellent attention which it receives. Every manufactory

of reasonable proportions has its own power plant and its own engineer, to whom is usually assigned the control of the heating system.

Considerations of economy and the before-mentioned idea of the owner, that *heating* is the preëminent feature desired in the application of the system in a factory, have much to do with the location of the apparatus. To secure economy in heating where improved ventilation does not enter into the question, the apparatus is frequently arranged so as to take its air-supply entirely from within doors, thereby simply turning the air over and over within the building. As the cost of ventilation is necessarily measured by the volume of air, at the temperature of the room, which is removed or caused to escape in a given time, it is obvious that this expense may be practically avoided by the above-mentioned plan of turning the air over and over. There is even then an incidental leakage resulting in a degree of ventilation considerably in excess of that occurring with any system of direct steam heating. To this end, in a one-story structure the apparatus should be placed as near the center as possible, so that the air may be drawn back to it from all sides.

Dependent upon the character and construction of the building, one of two general methods of distribution may be adopted. The first and most common is by a more or less extended system of metal ducts or pipes, almost universally constructed of galvanized iron on account of its durability. Such a system is the only one practicable in wooden structures. In brick buildings, particularly those of two or more stories, brick ducts and brick vertical flues are the most convenient, and, as usually applied, do not encroach upon valuable interior floor space.

The one-story structure with brick, wood, or metal sides, with sloping roof surmounted by skylight or monitor, forms to-day the model for the foundry and the machine, boiler, or blacksmith shop, while its use is rapidly extending to other trades. In such a building some arrangement of galvanized iron distributing-pipes is compulsory, for the brick duct and flue become too expensive proportionally to the cubic contents to be heated.

In comparatively narrow wooden structures, where it is a question of galvanized iron pipe or nothing, the main distributing pipe extends lengthwise of the basement and there connects with risers carried up alongside of the supporting columns of the building, from which the air is discharged towards the walls through properly located outlets about 8 or 9 feet above each floor.

The ideal installation of the blower system is in the three or four story brick factory of the type of the ordinary cotton mill, where the heated air is conducted from the apparatus through the basement to the bases of special pilaster flues located at regular intervals along one side of the building.

Figure 1 (p. 108) will serve to show the general construction of the duct and detail of a flue. The duct itself is constructed of brick, extending along the interior of the basement wall, and is provided with either a flat or arched top of approved and air-tight material, or is made quadrant in form, thereby securing for a given expenditure of material the maximum area for passage of air.

At distances varying from 40 to 75 feet, the piers between the windows are carried out and form the pilaster flues. Upon each floor, at least one foot below the main floor timbers which are supported by the piers, there is placed in each flue a special damper, as represented in Figure 2, which, as it is opened, extends into the flue and acts as a deflector to throw a portion of the air into the room, this proportion being controlled by the operating mechanism.

Most prominent among the buildings in which the ventilation may be considered of primary importance are those in which persons remain for several hours closely seated and practically inactive, as is the case with an audience in a church or theater and with the pupils in a schoolroom. Here, the *per capita* air space in the room is at its minimum. In the best modern schoolroom there is usually an allowance of 250 cubic feet of space per occupant; but in many theaters and halls this figure is reduced as low as 75 to 100 cubic feet to each person.

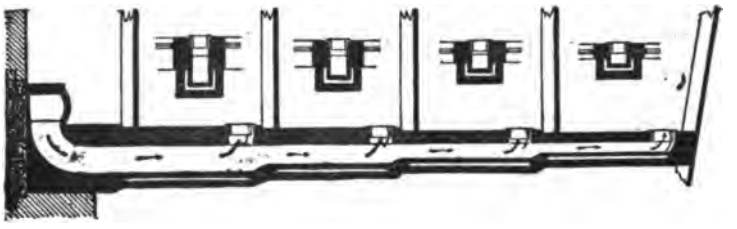
In the ordinary schoolroom a supply of 30 cubic feet per head per minute would necessitate changing the entire volume of the room once in about eight minutes, while in a hall with only 75 cubic feet of space for each member of the audience such a supply of air would require a complete change once in every two and one half minutes.

It is extremely difficult, in fact practically impossible, to so introduce such an excessively large volume of air under these latter conditions without creating objectionable draughts about the occupants.

In this climate a perfect system of heating and ventilation applied to a building of the aforementioned class, should,

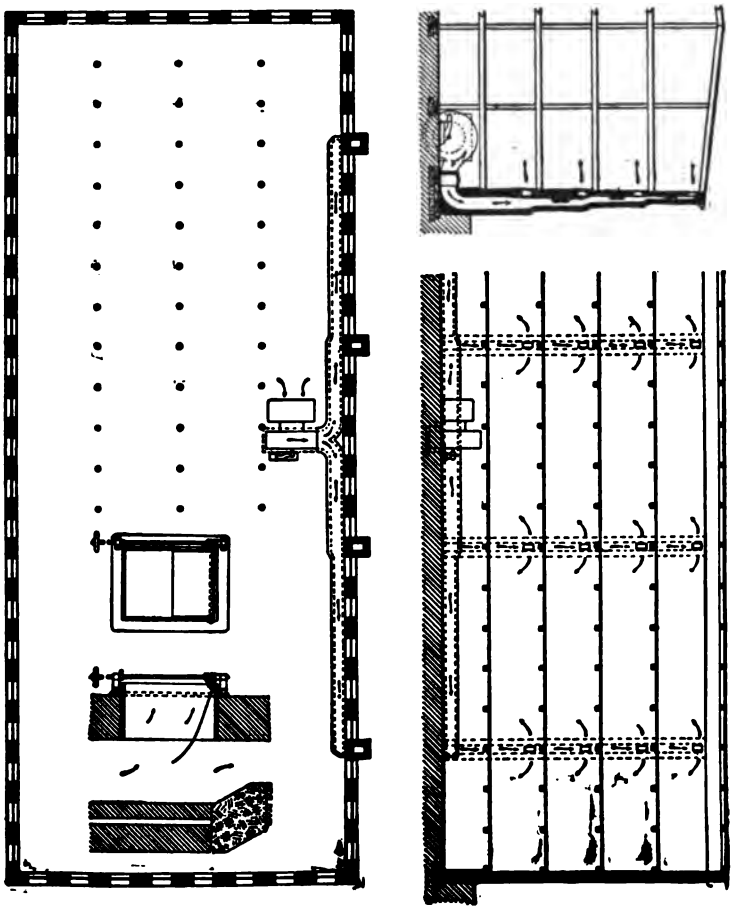
First, maintain within each room a mean temperature of 70° F., irrespective of changes in external temperature, with a total variation

FIG. 1.



DETAILS OF INSTALLATION IN A BRICK FACTORY.

FIG. 2.



of not over 2° above or below this mean in any occupied portion of the room.

Second, supply to the room, under all conditions of indoor and outdoor atmosphere, a constant predetermined volume of air, and deliver it without creating objectionable draughts and in such a manner as to be thoroughly and efficiently distributed throughout the apartment.

This second requirement may be even so exacting as to demand a constant indoor temperature, with variable supply of air proportioned to the number of persons occupying the room at any given time. Assuredly, with no arrangement or device can the air-supply be more readily proportioned to the requirements than with the blower system. Doubtless at the present time more attention is being given to improvement in schoolhouse ventilation than to that of any other class of structures; therefore a discussion of the application of the blower system to buildings of this type must throw a strong side light upon the methods to be adopted in all so-called halls of audience.

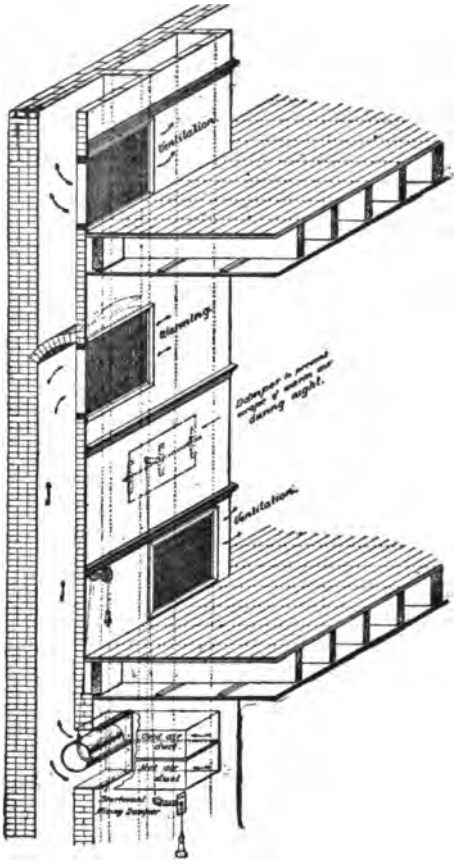


FIG. 3. ARRANGEMENT OF HEAT AND VENT FLUES FOR SCHOOLHOUSE.

The ordinary schoolhouse, with its brick partition walls, presents a most excellent opportunity for the economical placing of the necessary flues, for they may be grouped along the interior walls and provided with inlet openings about 8 feet above the floor and vent openings at floor level. A flue serving to supply hot air to the first floor may, by the insertion of a header above the heat opening, serve also as a vent flue for the room above. This arrangement is indicated in Figure 3.

By making the area of the vent register and flue the same, respectively, as that of the supply register and flue, the discharge of air — at a lower velocity than it enters — is sufficiently restricted to produce a plenum condition within the room, not only preventing inward draughts, but compelling the surplus of air to escape through cracks, crevices, and even through the porous walls.

The varying exposures of the rooms of a school building require that more heat shall be supplied to some than to others. The sunlit, southerly room, perhaps still more favored by being over the boiler, may be kept perfectly comfortable with a supply of heat that perchance will barely maintain a temperature of 50° to 60° F. in a room on the opposite side of the building, exposed to high winds and shut off from the warmth of the sunshine. With a constant and equal volume of air supply to each room, it is evident that its temperature must be directly proportional to the cooling influences within and around the room, and that no building is properly heated and ventilated where the temperature cannot be varied without affecting the air-supply.

To this end, air of a given temperature may be conducted to the base of each flue and there tempered to a degree suitable to the requirements of the room supplied. Two methods appear:

The older arrangement consists in heating the air by means of a primary coil to about 60° F., or to the minimum temperature required within the building. From the coil it passes to the bases of the various flues, and is there still further heated by secondary or supplementary heaters.

Such an arrangement is operated in the Walker Building of the Institute, where distribution ducts are omitted, and the entire subbasement serves as a large plenum chamber containing air under slight pressure heated to about 60° F. by the main coil.

Under the second and more recent method a single heater is employed, the supplementaries are discarded, and all the air is heated to the maximum required to maintain the desired temperature in the most exposed rooms, while variety in temperature of air supplied to the other rooms is secured by mixing with the hot air a sufficient volume of cold air at the bases of the respective flues.

This result may be best accomplished by designing a hot blast apparatus so that the air shall be forced rather than drawn through the heater, and by providing a by-pass through which it may be discharged without being heated. An example of this type of apparatus

is shown in Figure 4, provision for the discharge of the unheated air being made above and separate from the heater pipes. Extending from the apparatus is a double system of ducts. At the base of each flue is placed a mixing damper, as shown in Figure 3, usually controlled by chain from the room above, and so designed as to admit either a full volume of hot air, a full volume of cold air, or to mix them in any desired proportion without affecting the resulting total volume delivered to the room.

Where perfect regulation, independent of the teacher, is desired, the damper may be operated by a thermostat in the room with which the flue connects.

The *hot and cold system*, as this is familiarly known, accomplishes at less expense, with greater rapidity and equal certainty, the results

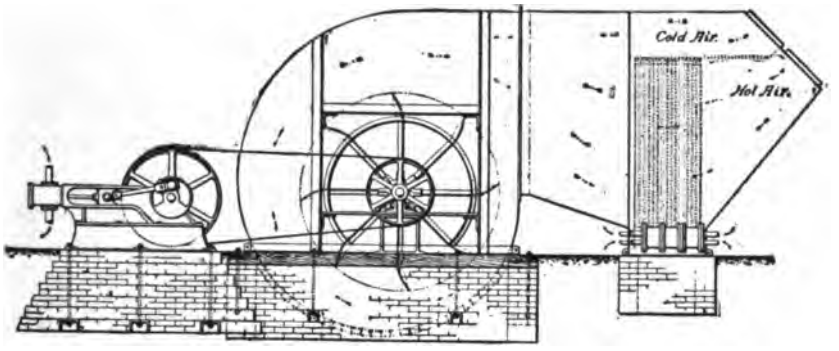


FIG. 4. HOT BLAST APPARATUS WITH COLD AIR BY-PASS.

obtained by the more complicated method previously described, and is being extensively introduced in the modern schoolhouse wherever the blower system is applied.

The hall and the church are in reality but enlarged schoolrooms as regards their treatment by the blower system. The same vital requirement holds; that the temperature must be maintained independent of volume of air admitted, while the difficulty of satisfactorily admitting the required air supply is increased by the closer seating of the audience.

The theater presents far more complication than the hall; its three parts — stage, auditorium, and lobbies — may at one moment be essentially one and the next be rendered practically independent. The auditorium is usually thoroughly protected by the lobbies or the walls of

adjacent buildings, so that the heat loss is reduced to a minimum and during a performance it becomes a question of cooling rather than warming the occupants.

A novel arrangement of the blower system is in operation in the New York Music Hall. The main concert hall, seating 3,000, and the recital hall, with a capacity of 1,200, are supplied entirely through perforated ceilings, whence the air passes down over the persons of the audience and escapes through a multitude of openings in floor and risers. This unnatural movement of the air against its own impulse must be facilitated by exhaust fans connected to the area beneath the floor in addition to the plenum fans for forcing in the fresh air.

The rapid improvement in theater ventilation certainly indicates that the enterprising manager sees therein another inducement to the theater-going public to patronize his individual house in preference to one where the air is foul and oppressive, although the dramatic attraction may be equally good.

The requirement of large air volume *per capita* in hospitals and asylums, particularly in contagious wards, necessitates positive and ample means which can only be met satisfactorily by the fan, standing as it does, capable, according to its size, of supplying any amount of air required.

The store with its extended floor areas, and the office building with its multiplicity of small rooms, call for arrangements peculiarly their own.

The ready adaptability of the blower system to diverse conditions forms one of its salient features. Not only is it a success as a heating and ventilating system, but as a means of drying materials of all kinds it has long been in use in many industries of this country. Lumber, wool, cotton, leather, fabrics, paper, and the like, are most expeditiously dried by this system, with its ample supply of warm air to furnish heat for vaporization of the water and the necessary absorptive power for taking it up and carrying it away.

The hot and oppressive summer day may be made more endurable in shop, office, or place of amusement by the mere operation of the fan and its resulting change of air within the room, while positive comfort may be secured by passing cold water through the pipes of the heater across which the air is drawn, or by exposing ice to the air currents prior to their entrance to the fan.

In place of the complicated and expensive appliances frequently

introduced in the textile mill for sufficiently humidifying the atmosphere to prevent the troublesome effects of frictional electricity, there is required with the blower system only a water spray in the main air duct.

The public at large has been slow to appreciate the necessity of ample and thorough ventilation, but in this State at least the building and State inspection laws keep the subject ever before the eyes of the proprietor, the architect, and his client.

As the mission of ventilation is to remove foul and supply fresh air, it is at once evident that in this process of removal there must be continuously carried from the room a large amount of heat, for all the air escaping must be of the same temperature as that of the room itself. This loss is incidental to any system or arrangement by which ventilation is secured, and it must be made good by imparting the necessary surplus of heat to the air admitted.

It is not strange, then, that the cost is greater for heating a well-ventilated room than one which is tightly closed.

The advantages of the blower system may be summarized under two main heads:

First, adaptability and convenience.

Second, efficiency and economy.

The early consideration of the system before the plans of the building are completed has, of course, much to do with its adaptability and the convenience with which it may be introduced.

The centralizing of the entire heating surface in a single room and within a single sheet-iron jacket avoids all danger by fire, prevents the possibility of damage by leakage, and removes all anxiety regarding the freezing incident to isolated coils. A single valve serves to control the temperature of all air admitted to the building, so that the thoroughly installed system, with its governed engine, automatic return water apparatus, damper regulator, and its thermostatic control, is rendered so completely self-controlling that the attendant's care is usually reduced to supplying sufficient coal to the boiler.

The system is positive in its action at all times, the air is put where it is wanted, not merely allowed to go. The pressure created within the building is sufficient to cause all leakage to be outward, preventing cold inward draughts and avoiding the possibility of drawing air from any polluting source within the building itself.

Absolute control may be had over the quality and quantity of air

supplied. It may be filtered and cleansed, heated or cooled, dried or moistened at will.

By means of the hot and cold mixing damper, the temperature of air admitted to any given apartment may be instantly and radically changed.

The *efficiency* and *economy* of the system must of necessity be considered under *first cost* and *running expense.*

Circumstances so decidedly alter cases that an arrangement economical and easy of introduction in one building may prove very expensive in another. In the majority of cases, however, the blower system, regarded simply as a method of heating, may be installed for less money than any other system of equal efficiency.

Wherever the flues can be formed in the walls and the distributing ducts are of moderate extent the system will figure less in first cost than any other capable of attaining the same results and of supplying the same amount of air. The primary cost of a fan is less than that of any other device for moving the same amount of air.

The large volume of air passing through the heater causes a condensation of steam so great that one foot of heating surface is rendered the equivalent in efficiency of three to five feet in the form of the ordinary direct radiator exposed in the room. This saving in heating surface offsets the additional cost of fan and motor.

As directly bearing upon this point, Professor Woodbridge has stated with regard to the installation in the Walker Building that the saving in piping due to rapid condensation in the coils, as there arranged, was sufficient to pay for the fan, together with an attached engine, had that arrangement been adopted.

In all fairness, the operating expenses of any system must be compared upon a basis of similar conditions. The blower system when taking its air from out-of-doors cannot be properly compared with any system of direct radiation, for in the latter is lacking the advantage of the ventilation incidental to the operation of the former. But when the blower system rehandles and reheats the air within the building without outside supply, the comparison becomes more reasonable, although there will still continue to be a considerable change of air due to leakage.

A six months' continuous test at the Globe Yarn Mills, Fall River, has presented data exceptionably valuable for comparison. Of two mills, nearly equal in size and equally exposed, one was fitted with an

overhead direct heating system, the other with the blower system. In mill No. 1 the average temperature was 70°, in No. 2, 78°.

The cost of fuel per unit of space warmed was, however, in the proportion of 100 in the direct heated mill to only 64 in the mill heated by the blower system.

The cost of janitorial service enters as an important factor in any building other than a manufactory. The blower system has been adversely criticised because of the experience required in its operation. In point of fact it has been attempted by committees and school boards to place the control of the system in the hands of men who could sweep floors and shovel coal but didn't know the difference between a boiler and an engine. It is not greater intelligence, but a different order of intelligence, that is required.

When exhaust steam that would otherwise be thrown away is utilized in the heater, its cost must be considered as practically nothing. The condensation in the heater of all the exhaust steam from the special fan engine reduces the cost for motive power to a minimum.

As to comparisons regarding cost of repairs much may be said pro and con; but the character of the machinery, its few parts, slow speed of engine and fan, the sectional construction of the heater, the lack of complication of valves, the concentration of the plant at one point, and the fact that it is under the care of one man, are greatly in its favor.

COLLEGE ATHLETICS.[1]

By FRANCIS A. WALKER, LL.D., President of the Institute.

I TRUST it will not be deemed beneath the dignity of this occasion that I should ask your attention to a few thoughts regarding college athletics. No theme is to-day of greater consequence to the colleges and universities of our land, whether as influencing school discipline or as affecting the standard of scholarship. Alike those who applaud and those who deprecate the growth of athletics must admit the importance of the subject.

The past ten years have witnessed a remarkable development in the direction indicated, which we may well pause to consider. The rising passion for athletics has carried all before it. Thus far, at least, there is no sign of reaction, or even of the exhaustion of the forward impulse. Honors in football, in baseball, and in rowing have come to be esteemed of equal value with honors in the classics, in philosophy, or in mathematics; and if the movement shall continue at the same rate it will soon be fairly a question whether the letters A.B. in the college degree stand more for bachelor of arts or for bachelor of athletics.

Among instructors and the governing bodies of our colleges there is a wide difference of sentiment on the subject. Some applaud, some doubt, some disapprove; others are simply dazed and know not what to think, or suspend all judgment waiting to see how much farther the rising tide will encroach upon the shore. In the larger community there is, perhaps, an even more pronounced divergence of opinion. Few college presidents or professors but see some good in the new movement and sympathize largely with the enthusiasm of their pupils. But there is a host of editors, preachers, and men of affairs in the outside world, and a host of parents and guardians more directly concerned, who are sure that it is all of evil; that the colleges are simply going wild over athletic sports, preparing the way for the downfall of the traditional system of education. To many of these it is a monstrous thing that large bodies of young men should give themselves up to contests of skill and strength, and that larger bodies still should find in these contests the chief interest of their college life.

[1] An address before the Phi Beta Kappa Society, Alpha of Massachusetts, at Cambridge, June 29, 1893.

Fairly to approach the subject, we need to consider the state of things which existed prior to the war of secession; in other words, to go back just one human generation, as a human generation is usually computed. In those days gymnastics held but a small, a very small, place in American colleges; while throughout the wider community there was almost no athleticism. The two most important exceptions to the latter statement were found in the occasional outlawed and always disreputable prize fight, generally with some international complication, genuine or manufactured, for the sake of stimulating public interest, and in a small amount of rather poor, unscientific boat-racing. Almost no honor was then given to a young man because he was strong, swift, courageous, or enduring. The college hero of those days was apt to be a young man of towering forehead, from which the hair was carefully brushed backwards and upwards to give the full effect to his remarkable phrenological developments. His cheeks were pale, his digestion pretty certain to be bad. He was self-conscious, introspective, and indulged in moods as became a child of genius. He had yearnings and aspirations, and not infrequently mistook physical lassitude for intellectuality, and the gnawings of dyspepsia for spiritual cravings. He would have gravely distrusted his mission and his calling had he found himself at any time playing ball. He went through moral crises and mental fermentations which seemed to him tremendous. From the gloomy recesses of his ill-kept and unventilated room he periodically came forth to astound his fellow students with poor imitations of Coleridge, De Quincey and Carlyle or of Goethe in translation.

Not all college heroes of those days were of this familiar type. Sometimes they were thunderous orators, more Websterian than Webster, who could by a single effort lift themselves to the full height of perorations which in the senate or the forum are the culmination of great arguments and of many a passionate appeal. Sometimes, though more rarely, the college hero was a delightfully wicked fellow, who did, or at least affected to do, naughty things, wrote satirical verses, was supposed to know life, and in various ways exerted a baleful fascination over his fellow students. But, however the type of the college hero might vary, speech-making, debating or fine writing were the be-all and the end-all of college training, as in the world outside the colleges speech-making, debating or fine writing were the sole recognized signs and proofs of greatness. Physical force, dexterity, and

endurance, capacity for action, nerve, and will power went for little, or went for nothing, so far as public admiration was concerned. Statesmanship itself was perverted by eagerness to seek occasions for oratorical display. Men of business, men of affairs, men of prudence, moderation and real ability were crowded out of our legislative halls by shrill-voiced declaimers who could catch the ear of a nation given over to the lust of words. "Sir," once said Daniel Webster, bending those tremendous brows upon a young man afterwards renowned among the great attorney-generals of the United States, "sir, the curse of this country has been its eloquent men."

What was the reason for this state of things regarding the college ideals of a generation ago, so strongly contrasted with what we see to-day? In part, bad physiology, or the absence of anything that could be called physiology, was responsible for it; but in greater part I believe it was due to the transcendentalism and sentimentalism of the last quarter of the eighteenth and the first quarter of the nineteenth century, which had created false and pernicious opinions concerning personal character and conduct. There was more than indifference, there was contempt for physical prowess. A man who was known to be specially gifted in this way was thereby disparaged in public estimation. If he were known to make much of it, he was more likely to be despised. It was taken for granted that he could not be good for anything else. Brains and brawn were supposed to be developed in inverse ratio. Affected notions about intellectuality and spirituality had almost complete control of the popular thought. The only things to be admired were mind and soul. "Mere bigness" was a favorite phrase of contempt. Strength was believed to be closely akin to brutality. Danger, positive danger, to spirituality, if not also to morality, lay in physical force and exuberant vitality. The same notions perverted the ideals of womanly grace and beauty. Robust vigor, a hearty appetite, and a ruddy complexion would have been deemed incompatible with the function of the heroine of a popular novel or a sentimental poem, or even with the part of a belle in society. Languor and pallor were attractive, delicacy of frame and limb was admired.

The set of notions referred to were doubtless closely connected with the political ideas of those days. It was an era of transcendentalism in politics. Political mechanism was disparaged. The philosophy of the age declared that a virtuous people would of themselves

make a good government. On the other hand, it was impossible so to organize the public force as to give a people a government that should be better than themselves. The maxim, "A stream cannot rise higher than its source," was a conclusive answer to all pleas for the scientific treatment of political problems. There was an affectation of indifference towards size and numbers in national life. Quality, not quantity, was in the eyes of the men of those days the sole test of the worthiness and the greatness of a people. Mass went for nothing. "Mere bigness" was here, as in the case of the individual, a term of infinite contempt. I never shall forget the rebuke, not unkindly meant or harshly spoken, which I received from a distinguished leader of public thought for boasting in a boyish vein about the extent of my country and the greatness of its resources.

The indifference toward or the dislike of athletics a generation or two ago was also largely due to the religious ideas and feelings of the time. The body was but a shell, a prison in which the soul was confined, and against whose bars its aspirations continually beat and bruised themselves. In another image, the body was a wayside barn in which the weary pilgrim laid himself down to rest till break of day. The flesh was an incumbrance to the spirit, a clog, a burden, a snare. Men had been told to "keep the body under," and perchance this was thought to be an easier task if that body were small and weak.

I do not mean to be understood as asserting that in those days the *mens sana in corpore sano* was never spoken of, or that there was no formal teaching of the duty of preserving bodily health. Such precepts, however, could have little effect against general tendencies of thought and feeling; and even among the most intelligent teachers of those days there was manifest a strong dislike, a sharp shrinking from all dwelling upon the physical basis of life, as savoring of materialism. As to acknowledging the relationship of man to the other orders of animals, that would have filled the pious mind with horror. The philosophy of the time had, indeed, to admit that the soul was in a degree conditioned as to its manifestations, and especially as to its influence upon others, by purely physical causes. But the soul itself was a thing transcendent, supernal, and self-sufficing, which when released from the clogs of flesh became at once as perfect, pure, free, and strong as if its tenement, while in residence here, had been more worthy of it.

All the notions referred to, so prevalent and so potent in at least

this section of the United States forty or seventy years ago, have gone, and gone together. Other ideas better suited to inspire a progressive civilization have taken their place. In part this has been due to the decay of superstitions derived from primitive savagery, in part to the effects of positive teaching, in greater part still to further experience of life. Biology has done its share; political education has done its share; the war of secession wrought its appointed work in the same direction. The men of to-day are generally agreed that they are likely to live long enough to make it wise to think a hundred times how they shall live, to once thinking how they shall die. The caravansary idea of existence has been abandoned. Man is not a pilgrim but a citizen. He is going to tarry nights enough to make it worth while to patch up the tenement and even to look into the drainage. This world is a place to work in; activity and development, not suffering or self-repression, its law.

The present generation has witnessed a wonderful diminution of spiritual self-consciousness. Better physiology, coinciding with some changes in popular ideals, has driven away the notions about the flesh as an incumbrance, a clog, a burden, a snare. It is seen that morbid or even merely feeble conditions of body tend to generate delusions, selfishness and susceptibility to the worst impulses. This is seen to be the case not the less because of the saintliness and the heroic constancy of a million sufferers from pain and infirmity. Hearty physical force may, indeed, consist with vicious desires, but it does not favor them. On the contrary, it does in a way and in a degree tend to diminish and to uproot them. Vicious desires are at their worst in feebleness and in morbid conditions of body. The sounder a man is, the stronger he is, the less — other things equal — is he subject to what is bad and degrading; the more pleasure does he take in what is natural, healthful, and elevating. To a perfectly sane man physically life itself becomes a joy. The relish for it does not need to be stimulated by the spices of vicious indulgence any more than a healthy appetite needs to be stimulated by the spices of the cuisine.

The sociological investigations into the causes and manifestations of crime, so actively in progress during the past few years, have added much to our knowledge of human nature in its self-respecting and law-abiding phases. The popular idea of the criminal once was that of a powerful brute, whose offenses against society resulted from an excess of physical vigor not counterbalanced by moral and intel-

lectual forces. As a matter of fact, it is now known that the prisoners in our jails are, as a class, undersized and undervitalized creatures, often with a deficiency of coördination between their faculties, sometimes with a minimum of control over their own actions and little adaptability to social and industrial functions. In the remarkable, the truly admirable reformatory enterprise of Superintendent Brockway at Elmira, gymnastics, regulated exercise and manual training perform a most important part.

In the revolution of thought regarding bodily development and physical prowess Mr. Beecher exerted a great influence. He it was who led off in favor of Muscular Christianity. During the controversy on that subject which attracted so much attention just before the outbreak of our great war there was, we must admit, not a little of exaggeration on the part of the advocates of physical culture. Many wrote and spoke as if all evil was to be worked off in the gymnasium and on the race track; as if every vice of human nature would exude through the pores of the skin if only perspiration was sufficiently active and long enough maintained. But in spite of much that was crude and foolish, these men had got hold of a great truth, and they did not let go until they had drawn it out into the light. The war of secession, also, which has been adverted to, came in to produce a vast change in popular sentiments and ideals, as it showed how much nobler are strength of will, firmness of purpose, resolution to endure, and capacity for action than are the qualities of the speech-maker and the fine writer, which the nation had once agreed chiefly to admire.

With this change of opinion regarding physical force and physical training in the individual has come a notable change in the political philosophy of the age. Larger experience of affairs has shown the folly of disregarding political mechanism. It is seen that it is hard enough to keep the balance of forces upon the right side, if every safeguard be adopted, every device used, and every means employed to give a preference to those who stand for order, decency, and honesty in the community. We are all now for making the devil fight with the sun in his eyes, instead of at his back, and with the advantage of the ground against him, instead of in his favor. We no longer with confidence hold that a virtuous people will necessarily have a good government. On the contrary, we recognize that a people virtuous above the average may, through a bad organization of the public forces, be made to act

almost as if they were the most cowardly and dishonest of their kind, as did our forefathers under the confederation of 1781–87. It is true that the stream may not of itself rise higher than its source, but by machinery we can send a stream a good deal higher than its source, and can make it do there more of vitally essential work than could all the waters of old ocean lying at their level. Instead of discarding political mechanism, therefore, the men of to-day believe in political machinery, like that of the Australian ballot system. They have learned that by means of it they can help the cause of righteousness, and at times turn the scale against the forces of evil. They not only believe in political machinery, they even believe in political machines, actual structures of wood and glass like the patent ballot-box, as important agencies to defeat the baser elements of society.

Again, "mere bigness" has ceased to be a term of contempt as applied to nations. Power in a people has become a thing admired. It is felt that it is indeed a glorious thing to have a giant's strength; nor is it longer believed that the disposition to use strength tyrannously grows with the opportunity. The idea once prevalent that its possession leads to brutality and insolence has not been borne out by the history of our own people. As the United States have grown more powerful they have grown more peaceful. In the early days of the republic our petulance, irritability, and pugnacity made us a nuisance and a pest among the nations. Swagger and unbounded brag characterized our earlier diplomatic history; while the war with Mexico, the cheap talk about "manifest destiny," and the filibustering excursions of the middle of the century seemed to point us out as a bad neighbor to the strong and a bully towards the weak.

Doubtless the slave power was in some degree accountable for this; but in greater measure it was due to lack of confidence in ourselves. We were always afraid that we were not going to be respected and treated with due consideration. We felt that we were looked down upon because we were young and small. No sooner was the mighty demonstration made of our courage and military strength in that great Civil War which will always remain one of the marvels of human history, than all this fell away from the nation like some loathsome rheum of childhood. To-day Canada and Mexico repose under the shadow of our irresistible power without an apprehension of harm or wrong, and it is even difficult to secure from an over-lavish Congress appropriations sufficient to enable us to make a decent show of naval

power in the great harbors of the world. It is true we have recently suffered an apparent brief access of jingoism, owing to certain unfortunate political complications; but the readiness with which the affair with Chile was adjusted and the general applause with which our flag was hauled down from the government house at Hawaii showed how superficial and how partial was the infection.

After this long and tedious statement of changes in the ideas and sentiments of our people in the several directions indicated, is it too much to say that we have, as a community, got down upon a sound, practical, sensible, worldly basis of life, much more promising for morality, for a steadily progressive civilization, for enduring enthusiasms — aye, for worthy aspirations and a true spirituality — than the unreal, morbid transcendentalism and sentimentalism of three, two, or even only one generation ago?

Among the many things, good or bad as people may esteem them, resulting from the changes in feelings, views, and ideals which have been indicated, are two which especially concern colleges and college men: The first is the general disappearance, most fortunate as I esteem it, of the literary societies formerly so flourishing, and the decay of oratory, declamation, and debate, which to many once made up the main interest of college life. The second is the rapid growth of athletics, in which immense honor is given to young men because they are strong, swift, enduring, and brave; in which the blood of the whole community is stirred by physical contests among the picked youth of the land as once it was only stirred by tales of battle. This last it is which has given me my subject to-day.

That the general introduction of gymnastics into colleges is desirable, few will deny. Young men of the college age whose occupations are largely sedentary should be encouraged to undertake systematic and extended exercise in order to correct the faults of the study and recitation-room, to expand their frames, and to promote an active circulation. Amherst is entitled to the high honor of being the first of the American colleges to make ample and suitable provision for students' needs in this respect. In 1861, under the presidency of Dr. Stearns, a gymnasium, large and well equipped according to the standard of those days, was placed upon the campus; daily exercise was made compulsory upon students not excused for cause, and a certificated physician was made director of physical culture and lecturer on physiology and hygiene. Few colleges have fol-

lowed Amherst in making exercise other than in the form of military drill compulsory; but fewer still now fail to afford their pupils opportunity for voluntary gymnastics to the top of their bent. The improvement wrought by these means in the physique of our college students does not need to be shown statistically; it is manifest to the eye of the most casual observer who remembers the former state of things. So far, there is no ground of debate; difference of opinion only exists with respect to the competitive sports and games which have grown up out of the newly awakened interest in physical prowess.

And here let me propose a distinction between gymnastics and athletics, which will be carried through the remainder of this discussion. That distinction is not one based upon etymology, but has reference to current usage:

Gymnastics are for individual training and development, with health strongly in view. Athletics take the form of competition and contest; emulation is their moving spirit, glory the aim.

As thus distinguished in their primary objects, athletics differ from gymnastics in two respects: First, by specialization, as when a man chooses his line of work in athletics — whether that be pole-vaulting, or hurdle-racing, or rowing, or pitching in baseball, or playing a certain position in football — and thereafter devotes his energies to working himself up to the highest point of efficiency in that line; secondly, by excess in the amount of exercise over what would be required or would be performed without the introduction of the spirit of emulation. So great is this excess that it may not unfairly be said that athletics begin where gymnastics leave off.

The effects of specialization in athletics are too much a matter of detail to be entered upon here. Suffice it, in a word, to say that they are not unlike those of specialization in industry — good and evil being mingled with, in general, the preponderance largely on the side of the good. Specialization affords to bodily exercise a more direct object and creates a far more intense and sustained interest. Moreover, for the best specialized work it is well known that at least a fair all-round development is almost always a necessary condition.

The excess of exercise in athletics over gymnastics, as we have defined these terms, is it of good or of evil? Is it a gain, or mere waste, or a positive injury? Gymnastics are a means to the end of health and vigor. Athletics become an end in themselves. With exceptions too inconsiderable to be enumerated, the athlete competing

for championship honors takes more exercise, often far more exercise, than is required for health and strength with a view to the peaceful and industrial pursuits of life. Vital force is consumed, not created, by the final contests in which he engages, and not infrequently by the training to which he subjects himself in preparation for them. The consumption of vital force in athletics, if we contemplate young men who are fully grown or nearly so, may be considered as of two degrees: First, where vital force is consumed in competitive sports and games as it might be consumed in study or in the production of wealth, without impairing the constitution or diminishing the physical endowment upon the strength of which the subsequent work of life is to be done; secondly, where exercise is carried so far and such violent exertions are made that not merely is the current supply of vigor used up in this way, but the constitution is undermined and injuries are sustained or exhaustion induced which result in leaving the man less healthful or less powerful through the remaining years of his life.

Of the severer forms of athletic competition and contest, which injuriously affect the constitution and permanently impair the vital force, but one thing can be said, they are evil and only evil. No earthly object, except the saving of others' lives or the defense of one's country, could justify such destructive exercises and exertions. I am disposed, however, to believe that there has been much of exaggeration in the public mind regarding this matter, and that instances of permanent injury from athletics are fewer than popular rumor or maternal anxiety makes them to be. The life history of the leading football players of the past fifteen years, notwithstanding the frequency with which contusions, sprains, and even broken bones occur in the tremendous struggles of that mighty game, makes up a record of vitality and activity in the period succeeding graduation which proves that, despite the occasional outcries of the press, this form of athletic contest works little enduring injury among thoroughly trained competitors. The more serious accidents of football generally occur in the beginning of the season and among players who have not passed carefully through the hardening stages of practice. Boat-racing is probably fraught with much more of real peril to its participants; yet a distinguished English statistician, studying the life history of three hundred and twenty "Oxford oars," has reached the conclusion that, even after making due allowance for the fact that

these were all at the start picked men, this great body of athletes showed a vitality distinctly above the average. Yet when all has been said, it is still beyond question true that in the present intense interest in physical contests there is a real danger to be guarded against, especially among the younger and less experienced competitors.

Of those physical contests which result merely in the consumption at the time of current physical force which would otherwise, or might otherwise, be devoted to study, we cannot dispose so confidently and summarily. To those who hold to the good old notion — the excellent, virtuous notion — that all young men go to college to make themselves scholars, it is, indeed, a great trial to have to contemplate a state of things in which no inconsiderable proportion of students treat scholarship as an object distinctly subordinate to gladiatorial prowess, and who really graduate, if they graduate at all, in athletics as a major, with classics, or mathematics, or philosophy, or something else as a minor, or perhaps we should say a minimum. Certainly this presents a view of college life which would have filled with horror the founders and early governors of our New England colleges. And it needs to be said at the outset, in dealing with this subject, that there are hosts of young men coming to college whose circumstances and means and views and plans of life are such that they cannot afford to treat their educational privileges in this way; who if they "go into athletics," in the accepted sense of that phrase, will sacrifice the one opportunity offered them; whose presence with their classes means a degree of sacrifice and self-denial on the part of parents and friends which would make it little less than profanation to waste an hour of the time which has been purchased at such a price. And yet, with due consideration for the rights and interests of students like these, college athletics confessedly as an end in themselves are not wholly of evil. Several things have to be considered before we are fairly in a position to pass judgment upon them.

The least important thing that can be said in their favor is that they afford enjoyment to vast numbers throughout the land; yet, for one, I would not treat even this consideration as unworthy of respect. The college athletics of to-day do wonderfully light-up the life of our people. The great recurring contests and the intermediate practice games and friendly competitions of the several teams give acute delight to a large and increasing constituency. This nation has long

shown the painful need of more in the way of popular amusement, of more that shall call men in great throngs out into the open air, of more that shall arouse an interest in something besides money-getting or professional preferment. In these respects college athletics have made an important contribution within the past few years. The marvelous rapidity with which football has spread and is still spreading throughout the Western and Southern States shows how eagerly it is welcomed as a relief to the monotony of life.

A stronger plea for college athletics is made when it is urged that they result in stimulating an interest in gymnastics among those students who do not engage in competitive contests, and also throughout the general community. The effect of this may easily be exaggerated. There is many a weak-kneed collegian who crawls out to witness the great baseball or football game of the year, looks on with intense delight, cheers the victors, if of his own side, as loudly as his limited lung capacity will permit, and then, when all is over, crawls back again to his room without so much as a conscious impulse to improve his own bodily condition. Yet it is certain that the cause indicated has an influence, and an influence not inconsiderable, for good. Admiration for manly prowess and the contemplation of fine physical development cannot fail to secure a much wider cultivation of gymnastics than would take place without it.

But, again, it must be said that the favorite athletics of to-day are, in great measure, such as call for more than mere strength and swiftness. They demand also steadiness of nerve, quickness of apprehension, coolness, resourcefulness, self-knowledge, self-reliance. Further still, they often demand of the contestants the ability to work with others, power of combination, readiness to subordinate individual impulses, selfish desires, and even personal credit to a common end. These are all qualities useful in any profession; in some professions they are of the highest value; and it cannot be gainsaid that it is the normal effect of certain kinds of athletic sports to develop these qualities among the contestants, as well as to afford impressive examples to the minds of the spectators. So genuine does this advantage appear to me that were I superintendent of the academy at West Point I should encourage the game of football among the cadets as a military exercise of no mean importance. It is the opinion of most educated Englishmen that the cultivation of this sport in the public schools of that country has had not a little to do with the

courage, address, and energy with which the graduates of Rugby, Eton, and Harrow have made their way through dangers and over difficulties in all quarters of the globe.

The last consideration which I would adduce to show that what is sacrificed in athletics is not all lost is that in the competitive contests of our colleges something akin to patriotism and public spirit is developed, with results, on the whole, of good. It is true that young men often carry their manifestations of zeal and devotion to their colleges too far. Yet, both as counteracting the selfish, individualistic tendencies of the age and as an antidote to the *nil admirari* affectations of our older colleges, it is a good thing that the body of students should now and then be stirred to the very depths of their souls; that they should have something outside themselves to care for; that they should learn to love passionately, even if a little animosity towards rivals must mingle with their patriotic fervor; that they should at times palpitate with hope and fear and anxiety in the view of objects which can bring to them personally neither gain nor loss.

Of the special evils of college athletics as now cultivated I do not purpose to speak at length. Some of those at present most clearly perceived are chiefly due to newness and rawness, and will of themselves disappear, in whole or in part, with time and further experience. Faults of method have yet to be eliminated; the traditions of the several games have yet to be created. For example, that regard for fair play, that respect for the rights of an opponent, that deference to the decisions of the umpire, so conspicuous in England, have there been the work of generations. They cannot be built up in a day with us. Yet our people are wonderfully quick to learn, especially to learn everything that conduces to harmony and adjustment of claims; the American is eminently and preëminently a political animal; and nowhere in the world are great crowds so orderly, peaceable, and good-natured as here.

One of the first things which should receive the attention of all lovers of fair play is the complete abolition, once and for all, of the unsportsmanlike system of organized cheering by great bodies of collegians grouped together for the purpose, with chosen youths of peculiar gesticulatory graces and preëminent lung power to start the movement and "deacon off" the shouting. Such a line of conduct, thoughtlessly resorted to in the heat of partisanship, is unworthy of educated men. It is unfair to the visiting team, who by all the laws of courtesy are

entitled to special consideration. How much more pleasing to the spectators, how much more creditable to the home college, if the stranger for the while within its gates were to be treated with something like the grace of antique chivalry!

Again, we may confidently expect that the machinery for carrying on sports and contests will undergo a steady improvement. We see a remarkable instance of the virtue of this in the appointment of the second umpire at football, which at once did away with certain tendencies that had threatened to make the game impossible. Audiences, too, must be trained to appreciate the finer points, to applaud good work by whomsoever done, and to be as virtuous as a Greek chorus, to the end that the game may be played by the players and not by the spectators. The coöperation of alumni is also to be invoked to give wisdom, weight, and temper to the action of the undergraduate bodies. Not least — nay, perhaps hardest of all — Faculties are to be educated, to avoid intermeddling and petty dictation on the one hand, and to sustain the claims of scholarship and enforce the right discipline of college on the other.

The last clause suggests one of the most important considerations related to the subject. Granting that something, and that not a little, of scholarship must be sacrificed if athletics are to be continued on anything approaching their present scale, may we yet believe that it is practicable to insist upon the requirement of at least respectable standing in the case of all who participate in intercollegiate contests? I believe that this can be done without interfering with the general movement, provided college Faculties are true to themselves, fair, frank and firm in dealing with the student bodies, and thoroughly honest in their treatment of the subject. I would not be understood to intimate that a certain amount of good sense would be out of place.

Perhaps it will not be taken amiss if I allude here to the results of my own observation in a sister university regarding which it has been my fortune to know more than I do concerning Harvard. At Yale, and especially in the scientific department, the Faculty appear to me to have been highly successful in preventing a total sacrifice of scholarly standing to intercollegiate sports. But a small proportion of the champion athletes in that university, a smaller proportion still in the scientific school, have been men at or near the foot of their classes — the sort of men who have to be hounded, threatened, and repeatedly conditioned in order to keep them up to the mark. Not a few

of them, from Kennedy to Hartwell, have been high up on the roll of academic honor. I attribute this excellent result to the thoroughly good understanding between students and the Faculty, to the absence of petty prescriptions and of all intermeddling as to details, and to the frankness with which the few positive requirements relating to the subject are stated and enforced.

I fear there is little in what has been here said to give comfort to those who distrust and dislike college athletics — little which intimates the opinion that the athleticism of to-day is only a reaction after the former total neglect of gymnastics, or a mere passing passion among our youth. But if we concede that these exercises and contests are to hold their place in American life, is there no stopping place, no point at which college authorities or the young men themselves, on their own motion, in their own discretion, for their own good, can say, "Thus far and no farther"?

I answer yes; there is such a natural stopping place. It is at the doors of the professional school. Among young men in the course of education, athletics should belong to the college stage; gymnastics to all stages. Whether this shall be done by regulation, or be left to the operation of forces working upon the minds of the individuals concerned, I believe the result indicated will, in either case, be reached. Already the undergraduate principle is widely though irregularly recognized; and the movement of opinion is still clearly in progress in this direction. Here at Harvard you have seen many a renowned champion put off athletics as he entered the law school or the medical school. The rule should be made of universal application; and it will require but a little more of discussion, but a little higher education of student-opinion, to bring this about. In and after the professional school, whether that be a school of law, of medicine, of divinity, or of technology, there should be no representative teams. The principle of competition and championship should be dropped. Individuals should continue, at their pleasure, to play tennis or cricket or football with their classes, with private clubs, or in town and county matches; or if teams be formed in such schools they should not be regarded as carrying the honor of their institutions around with them. Such teams should not expect victory. They should play for exercise and for the fun of the thing, and should accept their inevitable beating with serenity and good nature, recognizing the fact that since they have taken up the serious work of pro-

fessional preparation for life they no longer have the time or the strength at command to make and keep them champions.

There is one remaining question regarding the athleticism of today, which I feel myself so little qualified to discuss that I did not even allude to it while enumerating the things that might be said in favor of competitive sports, or at least in deprecation of the hostile criticisms directed upon them, which, however, here in closing I would fain propose to your sounder judgment and keener thought.

It is whether the college athletics, which so many approve and so many condemn, have not after all a deeper significance — whether this remarkable outburst of enthusiasm for physical development and for the perfecting of the human body is not related, perhaps vitally and intimately, to the growth of a feeling for art in this new land of ours. No classical scholar will for a moment admit that it was an accidental coincidence that the nation of the Old World which pursued athletics with the most passionate eagerness, which showered honors upon the victor in running or in wrestling not inferior to those which it gave to the author of an accepted tragedy — that nation whose tribes came by long and perilous journeys over stormy seas to witness the great athletic competitions by the banks of the Alpheus or on the Crissæan plain — was the same nation which carried the arts, and especially the plastic arts, to the highest point of perfection ever attained.

If, indeed, there is believed to have been a vital connection between these seemingly diverse manifestations of Grecian life, who shall say that the remarkable enthusiasm for physical training and the intense interest in athletic contests which have been so suddenly developed in our country may not be clearly seen a generation hence to have accompanied, and that through no accidental association, the elevation of art to a far higher and nobler place than it had before occupied in the thoughts and affections of our people? The life class is the true school of the artist. The greatest of all who bear that name have been men who revered the human form, made it their chief study, and found in it their highest delight. If in truth this sublime passion is taking possession of the nation, who shall estimate at a price the worth of that inspiration? The vision of the Apollo may yet rise to the view of thousands out and up from the arena at Springfield, as erst it rose before the thronging multitudes of Olympia.

THE HYDRAULIC LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

By DWIGHT PORTER, Ph.B., Associate Professor of Hydraulic Engineering.[1]

Received July 10, 1893.

This laboratory has been arranged and equipped upon an extensive scale for experimental researches and practical tests in hydraulics. The apparatus is used by the students of nearly all the engineering courses in regular laboratory exercises, during which they work in sections no larger than strictly necessary for conducting the particular experiment in hand. Such work is designed to give the students a practical demonstration of laws with which they have become familiar in a theoretical way only, to acquaint them with the appearance and behavior of certain standard forms of apparatus, and to teach them the methods and precautions commonly necessary in hydraulic experiments. The time allotted to any one variety of work is what seems sufficient fairly to attain the above ends, and no more, it not being proposed in class exercises to make the young men adepts, nor in general to achieve results in those exercises of especial scientific importance. In connection with thesis work, or the studies of post-graduate students, special apparatus is every year devised and installed suited to original investigations and to the securing of results of permanent interest and value.

The space devoted to the hydraulic laboratory covers about 30 x 50 feet on each of the two lower floors of the engineering building. The general arrangement of pipes and apparatus on the second floor of the laboratory is shown by the plan (Figure 1), and the view (Figure 2). The primary source of water supply is the city main, but it is rarely that draught is made directly upon this during an experiment, water being directly supplied from pumps, which in turn draw from a large receiving pit sunk below the basement floor, the discharge from all experiments finding its way to the pit and thus being used over and over. Several pumps are in use — steam, rotary, and centrifugal — sup-

[1] Abstract of paper read June 14, 1893, at the 12th annual meeting of the New England Water Works Association.

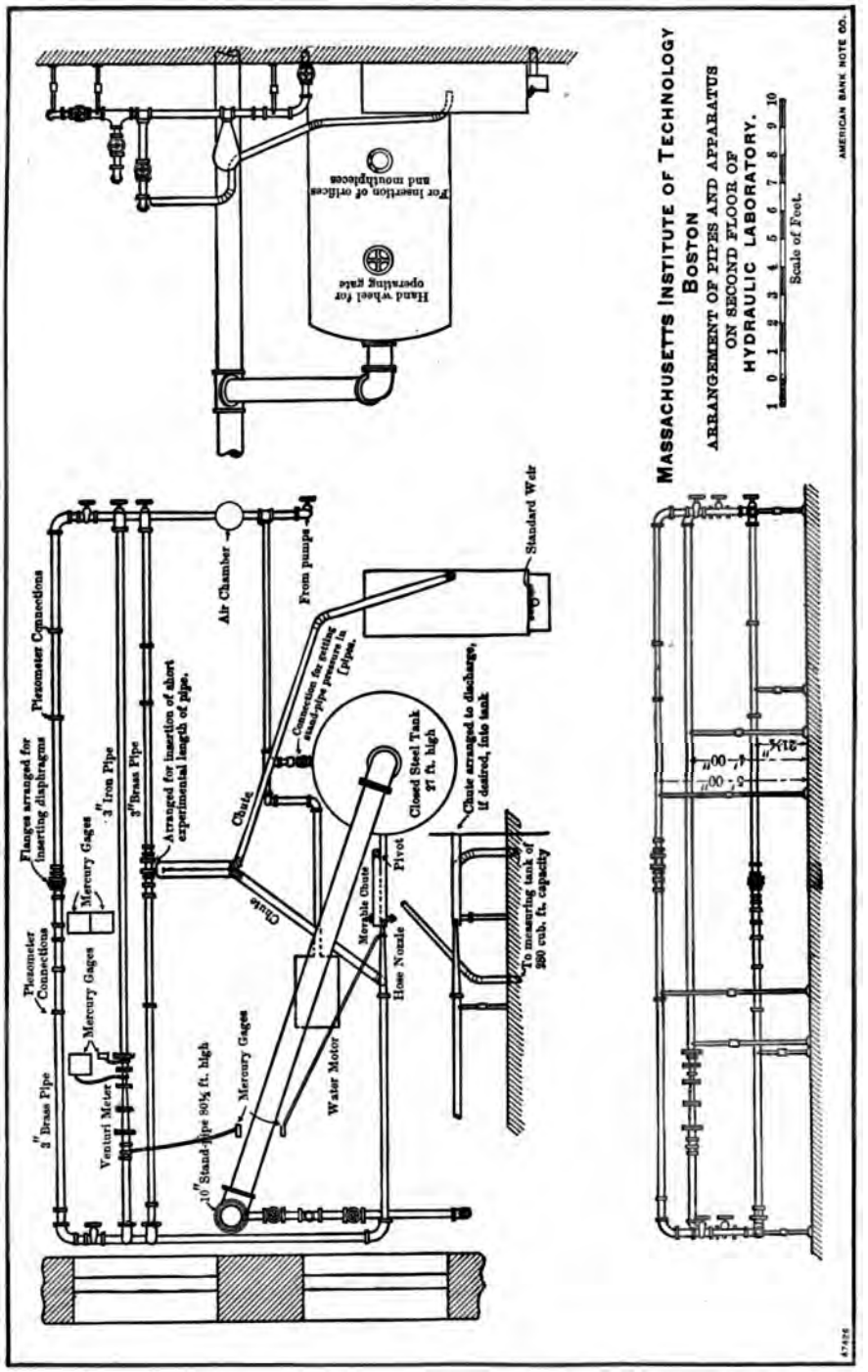

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
BOSTON
ARRANGEMENT OF PIPES AND APPARATUS
ON SECOND FLOOR OF
HYDRAULIC LABORATORY.
Scale of Feet.
AMERICAN BANK NOTE CO.
Hand wheel for operating gate
For insertion of orifices and mouthpieces
Standard Weir
From pumps
Air Chamber
Piezometer Connections
Flanges arranged for inserting diaphragms
Mercury Gages
3" Iron Pipe
3" Brass Pipe
Arranged for insertion of short experimental length of pipe.
Chute
Connection for testing steam-pipe pressure in Lipps.
Closed Steel Tank 21 ft. high
Chute arranged to discharge, if desired, into tank
Pivot
Movable Chute
Hose Nozzle
To measuring tank of 800 cub. ft. capacity
Water Motor
Mercury Gages
10" Stand-pipe 80½ ft. high
Venturi Meter
Piezometer Connections
1" Brass Pipe

FIG. 1.

plying the different apparatus. In order to secure a more constant pressure than that from the pumps, for certain kinds of experiments, a ten-inch standpipe, shown in plan in Figure 1, eighty feet high, has been built, reaching to the top of the building. The supply to this from the pumps may be so regulated by valves and overflows conveniently arranged on each floor that the head shall be kept at any desired point during an experiment, with a fluctuation of scarcely a hundredth of a foot. Many of the pieces of apparatus have been so arranged that they can be run at will under pressure either from the standpipe or directly from the pumps.

An important feature of the plant is a closed steel tank, five feet in diameter and twenty-seven feet high (Figures 1, 2, and 4) extending from the basement floor upward through two stories. It is connected at top and at bottom with the standpipe previously mentioned, and at four points on each floor is arranged for the insertion of orifices, free or submerged, mouthpieces and other fittings, and for connections with motors and experimental pipes. It is fitted with hydraulic gates so planned that an orifice, for example, may be quickly exchanged for another without the necessity of drawing down the water in the tank.

For certain experiments on the flow of water through pipes three lines of three-inch pipe (Figures 1 and 2) have been erected. One of these is of iron, with a Venturi meter, shown on the right of the foreground of Figure 2, inserted in its course; the other two are of brass, very carefully made, with piezometer connections of approved form at sundry points. One of the brass pipes is arranged for the insertion of diaphragms with orifices of various sizes, and the other for the insertion of short experimental pieces of pipe provided with side orifices, branches, or other devices. The discharge from the various pipe lines passes finally through a hose nozzle, with pressure-gauge connection to be used in determining the coefficient of discharge. The nozzle discharges (Figure 1) into a movable double chute, through one branch of which the flow may be wasted until it is desired to begin an experiment, when the other branch may instantly be thrown into the path of the jet and the water directed through the floor into a measuring tank beneath.

For delicate observations upon the velocity at any given point in flowing water, the laboratory contains three different instruments (Figure 3) embodying the principle of the Pitot tube. Two of these,

for use, respectively, in jets from nozzles and in streams flowing under pressure through pipes, are the property of Mr. John R. Freeman, by whom they have kindly been placed at the command of the Institute. The third, for jets from standard orifices, has been designed especially to use on the large tank which has been described, and one in use is shown by Figure 4. In each case the pressure of the flowing water due to its velocity is transmitted through a minute orifice and a connecting tube to a mercury gauge, the reading of which indicates the velocity at the tip of the tube. A simple attachment to the last-mentioned of these devices has permitted measuring the shape of the jet and the size of the contracted vein with the greatest nicety.

For measuring the quantity of water discharged during experiments the common method employed is that of weighing, the temperature of the water being at the same time observed. Thus, in determining the coefficient of discharge of standard orifices, the flow from the orifice passes into a large cask, with ample discharge pipe and quick acting valve at the bottom, and thence into another and similar cask underneath resting directly upon scales. The upper cask serves for temporary storage while the contents of the lower one are being weighed and discharged. By this means, with casks of moderate size, it is not difficult to weigh continuously at the rate of 40,000 or 50,000 pounds of water per hour. Again, the discharge from experiments on the second floor may be diverted through chutes to any one of several measuring devices on the floor below. One of the most important of these is a cylindrical steel tank six feet in diameter and ten feet high, capable of holding some 280 cubic feet of water. This tank is conveniently placed for drawing off and weighing the contents, and is by this means calibrated. In order to determine the quantity discharged into the tank in any experiment it is then necessary only to read a glass gauge attached to the tank and provided with sliding sight and vernier. For more indirect determinations of quantities of water the laboratory contains a number of weirs of different lengths, up to four feet, a calibrated orifice tank, Venturi and other water-meters, nozzles, and standard orifices.

The pieces of apparatus which have been mentioned will suggest to the mind a great variety of experimental work to which they are suited, and to much of which they have actually been applied. The laboratory further contains a Pelton water-motor, a small Swain turbine, a Douglas hydraulic ram, and a variety of dynamometers, mer-

cury gauges, piezometer fittings, etc. Figure 5 is a view of a Swain turbine being tested by students. There have also been placed in the laboratory a large number of finely constructed orifices and metal pieces of sundry descriptions which were used many years ago by Uriah Boyden and James B. Francis in their famous experimental work at Lowell.

The laboratory has been designed with a view to extensive further developments, important advances in which are likely to be made every year. It has been steadily taxed to its utmost capacity, both for regular class exercises and for thesis work, and fully commends itself as a substantial aid in engineering education.

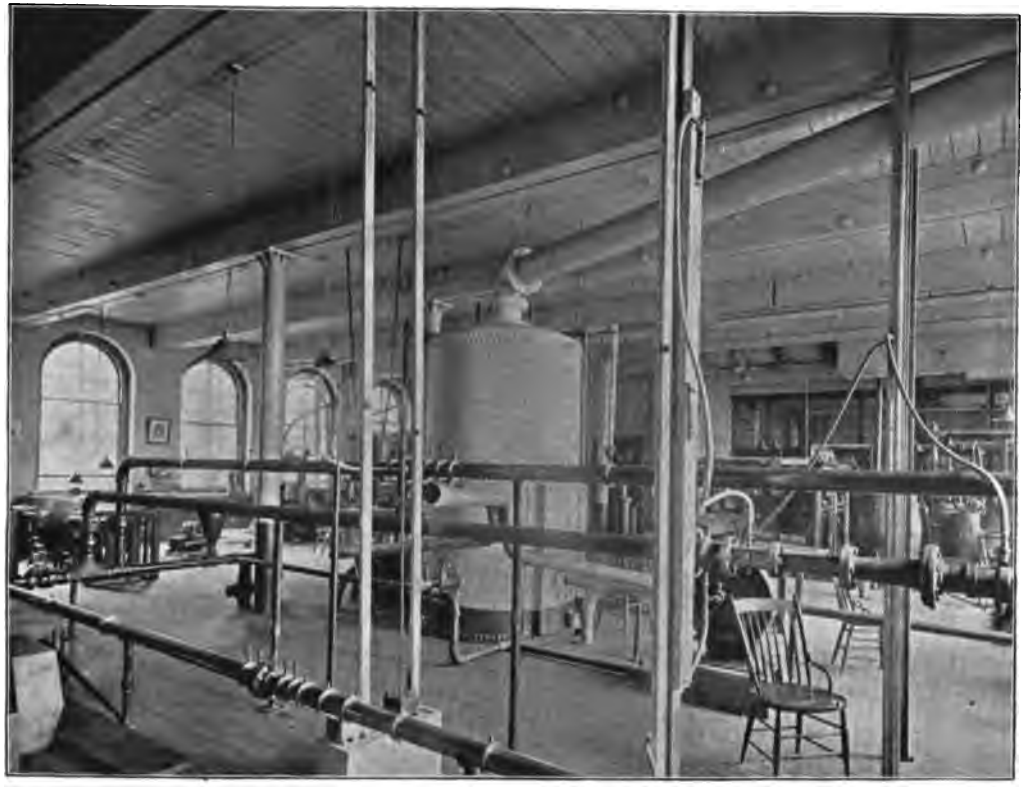


FIG. 2. VIEW OF SECOND FLOOR OF HYDRAULIC LABORATORY.

FIG. 3. FORMS OF PITOT TUBES USED IN EXPERIMENTS ON THE VELOCITIES IN FLOWING WATER.

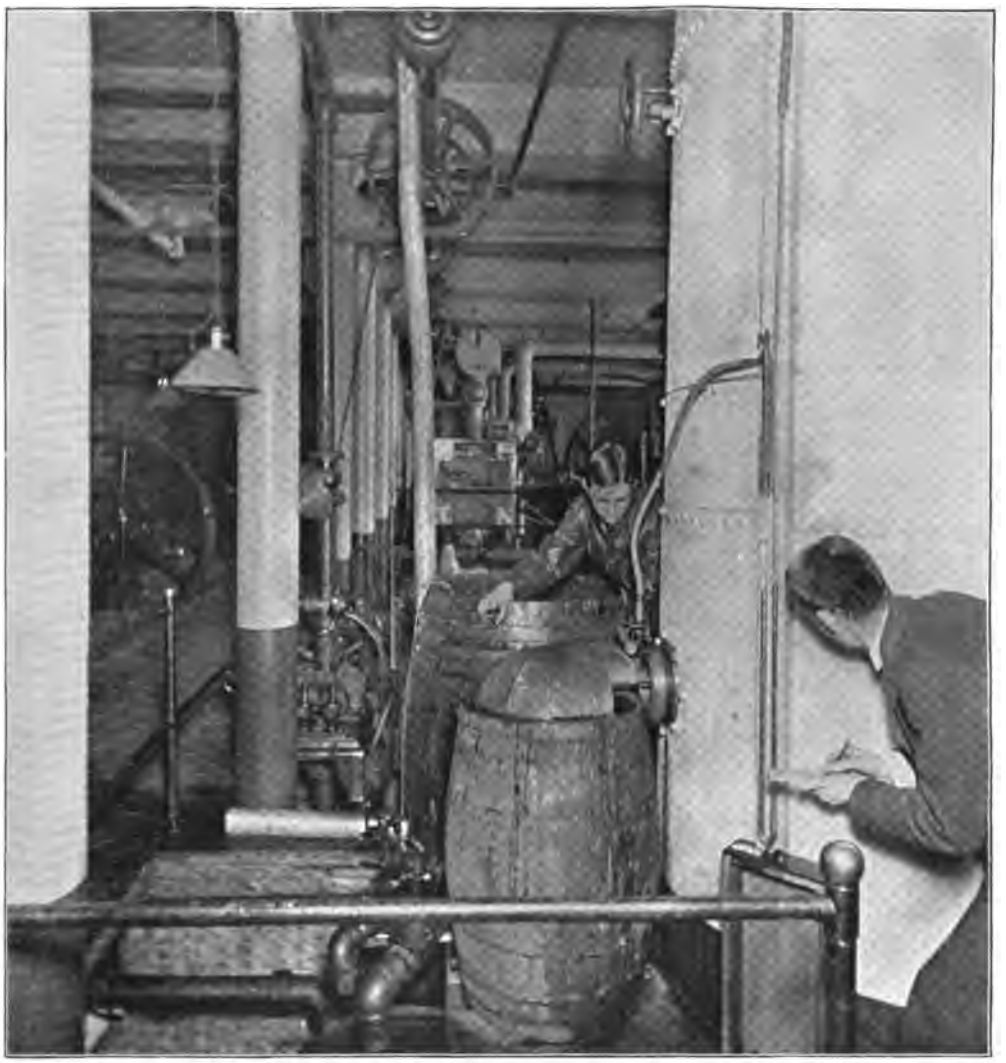


FIG. 4. STUDYING VARIATIONS OF VELOCITY IN A JET FROM A STANDARD ORIFICE BY MEANS OF A PITOT TUBE.

FIG. 5. STUDENTS TESTING A SWAIN TURBINE.

ADDITIONAL NOTES ON THE PRISMATIC STADIA-TELESCOPE.[1]

By ROBERT H. RICHARDS, S.B.

Received May 3, 1893.

In October, 1891, I read a paper before the American Institute of Mining Engineers[2] on a "Hand-Telescope for Stadia-Work," and promised to report at an early date some results showing the degree of accuracy attained with the instrument. I am now able to report on these results and also on certain improvements that I have made in the target since the first paper was read.

I may say that I prefer the title "Prismatic Stadia-Telescope" to that used in my earlier paper, for while the instrument can be used with perfect satisfaction for short sights up to, say, 300 to 500 feet when held in the hand, it is impossible to read much longer distances without the use of a tripod as a steady support for the instrument.

Results are here given upon four combinations of prism and telescope.

No. 1. A telescope made by Alvan Clark & Sons, 3-inch objective, 28 inches focal length, magnifying 60 diameters, the prism covering half the objective:

Feet measured by tape.	Reading of the rod.	Distance reduced to feet.	Reading of rod proportional to 100 feet.
127.66	1.1825	100	.92629
211.35	1.9585	100	.92666
326.59	3.0265	100	.92669
484.88	4.4925	100	.92652
606.91	5.6225	100	.92641
			Average, .92651

[1] A paper read at the Montreal Meeting of the American Institute of Mining Engineers, February 21, 1893.

[2] Read also before the Society of Arts; see Technology Quarterly, 5, 56.

The value of this prism, therefore, is .92651 feet on the rod for 100 feet of distance, or 1 foot on the rod corresponds to 107.931 feet of distance.

No. 2. A Bardou telescope having a 1-incn objective, magnifying 20 diameters, and a prism covering half the objective:

Feet measured by tape.	Reading of the rod.	Distance reduced to feet.	Reading of rod proportional to 100 feet.
127.66	1.1825	100	.92628
211.35	1.9585	100	.92666
326.59	3.0265	100	.92608
484.88	4.4875	100	.92548
1613.15	14.950	100	.92675
			Average, .92634

This average is obtained by discarding the fourth reading, which is manifestly not quite as accurate as the others.

The value of this prism, therefore, is .92634 feet on the rod for 100 feet of distance, or 1 foot on the rod corresponds to 107.97 feet of distance.

No. 3. A Bardou telescope having a 1-inch objective, magnifying 20 diameters, and a prism covering half the objective:

Feet measured by tape.	Reading of the rod.	Distance reduced to feet.	Reading of rod proportional to 100 feet.
127.66	.8345	100	.65368
211.35	1.3815	100	.65365
326.59	2.1325	100	.65289
484.88	3.1695	100	.65366
			Average, .65366

This average was obtained by discarding the third reading, which is obviously an imperfect observation.

The value of this prism is .65366 feet on the rod for 100 feet of distance, or 1 foot on the rod corresponds to 152.29 feet of distance.

No. 4. A small cheap telescope having a $\frac{3}{4}$-inch objective, magnifying 10 diameters, and a double prism divided in halves, one half being set with the edge up and the other half with the edge down,

giving, therefore, two bent rays instead of the usual arrangement of one bent and one direct ray:

Feet measured by tape.	Reading of the rod.	Distance reduced to feet.	Reading of rod proportional to 100 feet.
15.97	.5	100	3.1308
31.99	1.0	100	3.1259
47.94	1.5	100	3.1289
63.95	2.0	100	3.1279
79.94	2.5	100	3.1273
95.99	3.0	100	3.1242
			Average, 3 1275

The value of this prism, therefore, is 3.1275 feet on the rod for 100 feet of distance, or 1 foot on the rod corresponds to 31.974 feet of distance.

The self-reading rod which has been devised for use with this prismatic stadia-telescope, and which gives perfectly satisfactory readings, is shown in Figure 1. Figure 2 shows the same rod while being read; the reading in this case is 234 feet. This rod has three stages of graduation; the largest space, namely, the space between the large numbers, 0, 1, 2, 3, etc., represents 50 feet; the single notch of the main scale, 10 feet; and the vernier which is brought down by the prism into juxtaposition with the main scale divides that space into units of 2 feet, while by the eye one can further subdivide to single feet.

Now, referring to the prisms tested as above, for No. 4, the three graduations of the rod that will be found best are 25 feet, 5 feet, and 1 foot. Such a target can be read easily when the instrument is held in the hand at 400 to 500 feet distance.

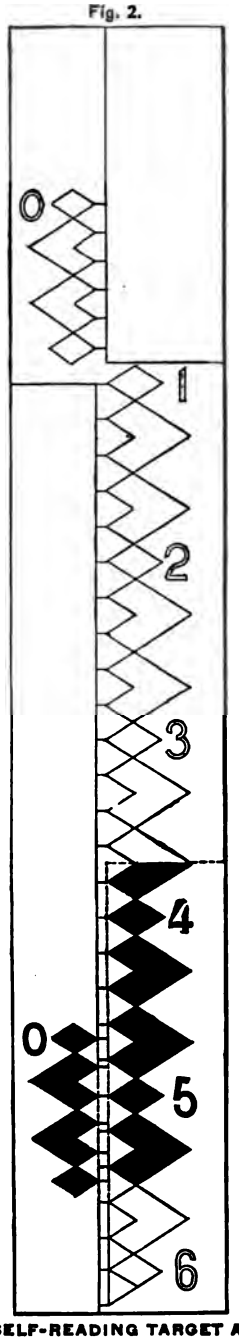
For prism No. 3, if the graduations of the target represent 50 feet, 10 feet, and 2 feet respectively, the target is a strong-reading one at 500 feet, but requires a tripod for the instrument. It can be read even at 700 feet, but is not strong at that distance.

For prism No. 2, the graduations of the target should be respectively 50 feet, 10 feet, and 2 feet; it will then give a strong reading at 800 feet from the tripod. If a 30-diameter telescope be substituted for the 20, the target will be good at 1,100 or 1,200 feet.

Fig. 1

SELF-READING TARGET AS SEEN BY THE EYE

Fig. 2.



SELF-READING TARGET AS SEEN THROUGH THE PRISM

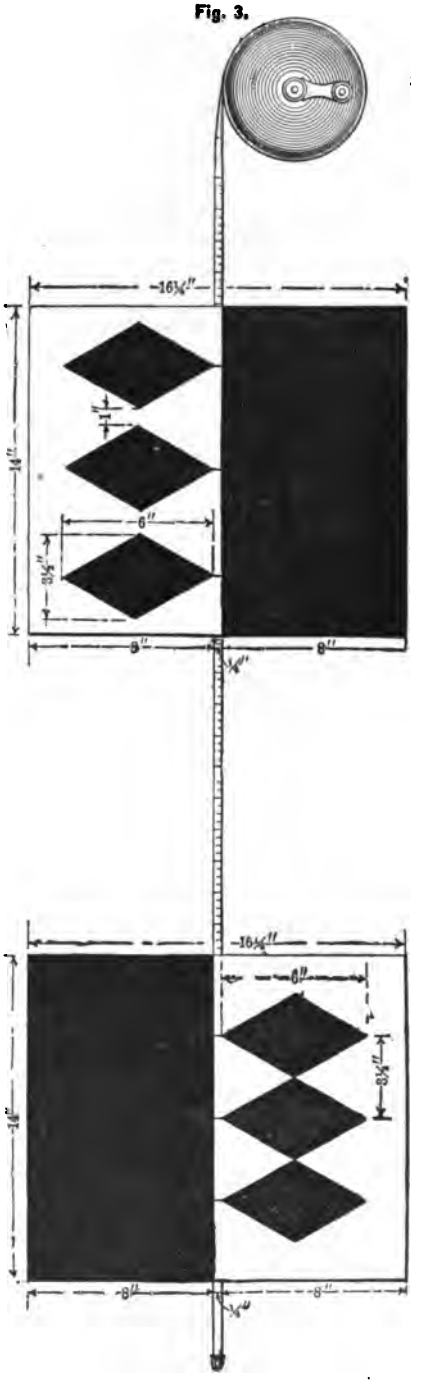
For prism No. 1, the graduations of the target should be respectively 50 feet, 10 feet, and 2 feet, and this target can be read at a distance of 1,500 feet or more. The rod, however, would be inconveniently long.

When the distances to be read are much greater than 1,000 feet, the two sliding-targets upon the tape (Figure 3) will be found more satisfactory. The coincidence here is between the two center diamonds, a very strong reading. (See Figure 4.) These targets may be read at distances varying with their size. A target of the dimensions given in Figure 3 can be read easily at 1,600 feet with prisms No. 2 and No. 3. It can probably be easily read to 2,500 feet with a 30-diameter telescope having a No. 2 prism, and probably also at a distance of 3,000 to 4,000 feet with a No. 1 prism.

If the sun be shining bright and hot, creating much flicker in the atmosphere, the instrument becomes unreliable for long distances. On the other hand, it breaks down for any distance, either long or short, if one target is exposed to bright sunlight, which causes a contraction of the pupil, while the other is in dark shade. On dull, cloudy days, the target may be read with great nicety at extreme distances.

The advantages claimed for this

Fig. 3.



TAPE-TARGETS AS SEEN BY THE EYE.

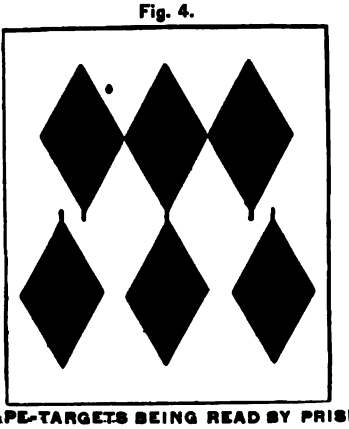
prismatic stadia-telescope, as compared with the usual forms read by spider-lines in the telescope, are:

1. The starting-point for the measurement is within the prism, instead of being at an imaginary point some distance in front of the objective.

2. Only one observation is required for measuring a distance, and there is therefore only one personal equation instead of two.

3. The portion of the target which is to be read is the only part that is distinct, it being unnecessary to hunt for the reading. (See Figure 2.)

Fig. 4.



TAPE-TARGETS BEING READ BY PRISM.

4. The reading is made in two ways, by convergence of the immediate points read and by double divergence of the contiguous points above and below. With the spider-webs, convergence only is used.

5. It would seem as if the probable error should be less where two diamond-points are juxtaposed than where a portion of the target is hidden by the thickness of the spider-line.

6. The prismatic stadia-telescope can be used from the hand for short distances, which is impossible with the spider-web instruments.

7. Long distances can be satisfactorily measured by the tape and sliding-targets, which is impossible with the spider-web.

ON METHODS USED AND RESULTS OBTAINED IN MAKING GERMICIDAL-EFFICIENCY TESTS OF A DISINFECTANT FOR USE IN RAILWAY SANITATION.

By WILLIAM T. SEDGWICK, Ph.D.

Received August 18, 1893.

The arrival of Asiatic cholera in the harbor of New York in the autumn of 1892 directed general attention to matters of public sanitation. The disease was brought upon steamships, and much of the alarm that was felt was due to the knowledge that cholera might be carried all over the land by the railroads. The importance of railway sanitation had long been known to experts, and the presence of cholera at our doors served to inform the public. Fortunately, in 1892, the disease was confined to New York.

Recognizing the probability of a recurrence of the danger and the possibility of a more serious invasion in 1893, and anxious to be ready for any emergency, the officers of the Pennsylvania Railroad Company determined to have thoroughly tested, with respect to its efficiency or germicidal power, a disinfectant of their own manufacture, which, since 1885, they have been using in their cars, closets, urinals, passenger stations, freight-houses, shops, etc., or wherever a liquid disinfectant is applicable upon a railway system. The extent and public importance of such disinfection may be realized from the fact that this company operates altogether nearly 8,000 miles of railway. It forms one of the principal avenues of communication between the principal seaports of the United States and the great West. It carries over its lines yearly many thousands of immigrants, and directly connects one with another the largest cities in the United States. It is therefore held to be one of the most important railway systems in America; and it has a reputation for careful and scientific administration.

I am informed by Dr. C. B. Dudley, Chief of its Chemical Department, that chemical studies on commercial disinfectants by this road began as early as 1880, and in 1884 these studies culminated in the

thorough examination of some twenty-six commercial disinfectants. In view of the multiplicity of materials offered in the market as disinfectants, and the very high price charged for many worthless compounds, it was decided to embody the results of all these studies in a specification for a disinfectant to be made for the use of the road. This specification was issued in February, 1885. A few years later, when the work of the Committee on Disinfectants of the American Public Health Association became available, this specification was revised accordingly, and the so-called P. R. R. Standard Disinfectant was brought up to date.

The disinfectant submitted to me for tests of its germicidal power was said to consist of a concentrated solution of chloride of zinc, chloride of copper, and bichloride of mercury, with a few drops of terebene. The terebene was added as a telltale, to inform the officers whether the disinfectant had been faithfully used, rather than as a disinfectant. I was also informed that the disinfectant contains one part in five hundred of bichloride of mercury and a little over 45 per cent. of chloride of zinc. The chloride of copper was added because a little copper salt was desired to fix sulphuretted hydrogen, and the chloride of zinc solution was made very strong on account of the well-known deodorizing properties of this material.

I am also informed by Dr. Dudley that this disinfectant is made by the railroad company, for its own use, under the supervision of the officers of its laboratory. Old battery zincs which are no longer useful in the batteries, muriatic acid, sulphate of copper, common salt, and bichloride of mercury are used in its manufacture. The actual cost of the disinfecting material in an eight-ounce bottle is about two and one half cents. The material is distributed to the service in wooden boxes, holding twenty-four bottles each, and in barrels. If these boxes and bottles are returned, the real cost to the different parts of the service is the figure given above. If the bottles are broken and the boxes destroyed the cost is somewhat greater. In barrels which are not returned the cost is somewhat less than in bottles, no labor being required for bottling. There were made and used on the whole Pennsylvania railway system during the year 1892 366 gross of eight-ounce bottles and 69 fifty-gallon barrels.

The specifications to which the disinfectant must conform are given as follows:

"Disinfectant for the use of the Pennsylvania Railroad Company

will consist of a neutral solution of the normal chlorides of copper and zinc and mercuric chloride put up in eight (8) ounce bottles and securely corked. Each bottle should contain 2,400 grains of zincic chloride, 120 grains of cupric chloride, 10.5 grains of mercuric chloride, and ten drops of a mixture of equal parts of terebene and turpentine."

The bottles must have pasted upon them the following "Directions for Use," a perusal of which will convey a good idea of the scope and the importance to the community of efficient railway sanitation:

DIRECTIONS FOR USE.

FOR USE ON CARS. — Empty the contents of this bottle into about one quart of water. With a sponge or waste, wash with the liquid all parts of the urinal, seat, and hopper, and the floor adjacent to them in the closet, allowing some of the liquid to run down the urinal pipes. The same solution should be used on the floors and woodwork of the whole car whenever washing with disinfectant is necessary. The carpets and plush of an infected car should not be treated with disinfectant, but should be fumigated instead.

FOR CLEANING PRIVIES, CLOSETS, ETC. — Empty the contents of this bottle into about one quart of water, and use as above. The disinfectant acts slowly on lead, tin, copper, brass, iron, etc., and it is not advisable to allow it to stand in the basins or traps. In the vault, use the disinfectant full strength, not less than half a dozen bottles at once, but it is better to disinfect privy vaults with crushed sulphate of copper, or chloride of lime, sprinkled freely over the mass.

FOR REMOVING BAD ODORS. — Empty the contents of this bottle into about one quart of water, and sprinkle the liquid in the place from which the odors arise; also saturate a towel, or other fibrous substance, with the liquid and hang it in the place from which it is desired to remove the odors. For use on towels, etc., a disinfectant without color can be furnished if desired.

IN CASES OF DIPHTHERIA, SCARLET, TYPHOID, AND TYPHUS FEVERS, CHOLERA, DYSENTERY, CONSUMPTION, ETC. — Place a little of the disinfectant, full strength, in the vessel which receives the excrement, or vomit, or throat discharge, and pour more of the disinfectant on the discharge after it has been received in the vessel. If the discharge soils the floor or furniture wash these soiled spots with the disinfectant mixed with water as above. Soiled bed and body linen, rags, or handkerchiefs used to receive discharges, and soiled clothing should be burned, or soaked in disinfectant diluted as above, for four hours and then rinsed with water.

FOR THE DEAD, WHERE DISINFECTANT IS NECESSARY. — Wrap the body in a sheet thoroughly saturated with the disinfectant full strength.

FOR ATTENDANTS ON THE SICK. — Empty the contents of this bottle into a pint of water, and wash the hands and other portions of the body, if soiled, with it, rinsing off with clean water. In sick rooms and hospital wards, wash all surfaces with the same solution.

☞ This disinfectant, when mixed with water, as described, will not injure the hands, but should not get into the mouth.

As has been stated above, in view of the probability of a fresh invasion of cholera in 1893, the officers of the road determined to be as fully prepared for it as possible, and accordingly, in December,

1892, Mr. Theodore N. Ely, then Superintendent, now Chief, of Motive Power, desired me to make a careful series of tests to determine, in the most rigid manner, the precise germicidal value of their standard disinfectant, and to suggest to them, if I could, how its efficiency might be improved.

In view of the fact that the composition of the disinfectant is well known, that it is not for sale, except to its employees or where the interests of the road are directly involved, and is not in any sense a proprietary preparation and, above all, impressed with the importance of the inquiry to the public welfare, I consented to undertake the investigation, although with reluctance because of the peculiar difficulties involved in all efficiency tests upon germicides. I was fortunate, however, in securing throughout the investigation the aid of Mr. Albert P. Mathews, S.B., Assistant in Biology at the Massachusetts Institute of Technology, to whose skill and devotion the work owes much of whatever value it may possess.

In the present state of opinion regarding the active cause of infectious disease, which holds that this is invariably due to specific microörganisms, it becomes simple in theory to determine the value of any germicide or antiseptic. It seems, at first sight, easy enough to test the efficiency of a disinfectant by simply observing under various conditions its germicidal power. But in arranging the details of the experiments difficulties arise which are hard to overcome.

It might be supposed that if we exposed known numbers of specific disease germs to the action of a fixed amount of the disinfectant for a definite period, and then made cultures from the mixture, we should readily settle the efficiency of the disinfectant at the given strength. But this is by no means the case; for, unless great care be taken to prevent it, we may carry over with the test sample of the mixture taken for planting enough of the disinfectant to inhibit later the development of the still-living germs. Errors of this kind are particularly insidious and very difficult to avoid. Again, there is reason to believe that cultures of the germs submitted to examination vary in their endurance considerably, particularly if these are of kinds which produce spores. As in the higher plants some fields of corn or oats are strong and vigorous while others are weak and sickly, so here it is important to know that the cultures or crops of bacteria with which we are dealing are fairly representative of those which devastate the human body.

The problem in this case was strictly one of germicidal and not merely antiseptic properties. For the preservation of food the problem is often one of antisepsis, but into disinfection this milder problem does not enter. The question is one of destruction, not inhibition, and may be stated thus: How efficient is the disinfectant as a destroyer of the germs of infectious disease?

The methods used in the examinations of the germicidal power of disinfectants have been almost as numerous as the observers, and the results obtained have varied widely. Koch has employed a silk thread dipped into the culture and then exposed to the action of the disinfectant. The thread was afterwards washed with sterile distilled water, and then planted on the surface of the plated medium or else sown in bouillon. Such a method is open to serious objection, as it is difficult to wash away all the disinfectant clinging to the thread and the slight amount left may continue to act antiseptically, and lead to erroneous conclusions.

Sternberg, in this country, has proceeded in a different manner. He exposes the broken-down beef tea, or pure culture of the bacteria in bouillon, to a known strength of the germicide for a given length of time, after which he transfers by peculiar flasks a certain small amount to a large amount of fresh alkaline bouillon and allows incubation to proceed. The objection to this method is that he inevitably introduces into the second culture medium an uncertain small amount of the disinfectant. The methods of Koch and Sternberg are both, at least in theory, somewhat untrustworthy, for the reason that the action of the germicide cannot be checked at once and because each introduces into his control medium some of the germicide.

It is self-evident that in testing any germicide it is necessary to stop its action quickly or to remove it wholly from the test medium. Only when we accomplish this can we hope to be sure of the results.

In solving the present problem we were guided by the work of those experimenters who had also recognized the necessity of freeing the bacteria after their exposure for the given time from the possible antiseptic influences of small amounts of the germicide thus carried over. Two reagents have hitherto been used for this purpose for antiseptics containing corrosive sublimate, namely, ammonium sulphide and hydrogen sulphide. Our problem, however, was not so simple. In the first place, it was not only necessary to test the antiseptic effect of the precipitant upon every specific germ to assure ourselves

that it was not itself more or less antiseptic; but in the second place, we were here not merely working with a dilute solution of the sublimate, but also with a strong solution of zincic and cupric chlorides, and if either of the precipitants mentioned were used there would be formed a heavy, flocculent precipitate likely to gather around the germs and drag them down, thus leading to serious error. Hence we were compelled to run control experiments with pure water in many cases, and sometimes with other precipitants, while at the same time carefully testing the antiseptic action of the precipitant itself.

As already stated, we endeavored to eliminate the various sources of error that had hitherto been recognized. The first question was that of the cultures themselves, and only the freshest cultures of pathogenic germs were used, since it is probable that such cultures are most nearly normal. We also satisfied ourselves that each culture was in a vigorous state, as indicated by the rapidity of its growth or the manner in which it formed spores.

The cultures of the specific bacteria used were subjected to rigid differential tests in order to establish the fact that they were really the germs in question. The culture of typhoid fever bacilli had been isolated not long before from the spleen of a woman dead of typhoid fever. The culture of anthrax was comparatively fresh, having been obtained from a patient in the Boston City Hospital. The culture of *Staphylococcus pyogenes aureus* was derived from one isolated a few days previous by Dr. W. T. Councilman, Pathologist to the Boston City Hospital. The culture of the *Streptococcus* of diphtheria was also derived from one isolated by Dr. Councilman a few days before it was used in these experiments. The culture of the cholera *Spirillum* of Koch was derived from one isolated by Dr. Dunham, of New York, from a case of Asiatic cholera there in September last. The culture of *Bacillus subtilis* had been in the laboratory for some time, but, as was proved by the resistant properties of its spores when subjected to heat, it was in a most vigorous condition. We may then safely conclude that the cultures employed in the tests were in a fresh and vigorous condition.

It is generally believed that mercury forms a more or less stable compound with albumen, though whether this compound is or is not soluble, and whether it is or is not effective in making the germicide powerful, is a matter of dispute. Vaughan contends that it is very poisonous, while others hold that such an envelope forming about the

bodies of the bacteria protects them from the further action of the germicide. How far these ideas are true, or how far they are important if true, is uncertain.

In the actual investigations we introduced a known amount of the fluid holding the germs in suspension into a known amount of the disinfectant, and at the end of a given interval transferred a small known amount of this mixture to a large amount of dilute ammonium sulphide which was used as the inhibitor, sometimes making control experiments with stannous chloride and at other times with water in the place of the ammonium sulphide. We used ammonium sulphide in preference to hydrogen sulphide as inhibitor, for the reason that the solution of the germicide was found to be decidedly acid, and thus we were forced to neutralize the acid at the same time that the mercury was neutralized. The use of any sulphide we adopted with hesitation, owing to the formation of a heavy flocculent precipitate; but by making control tests with stannous chloride, which simply neutralized the mercury and did not affect the other chlorides, and by using water in the place of the sulphide, we came to the conclusion that, in spite of this danger, the ammonium sulphide was the best inhibitor we could use, although it may be that further experiment would show the stannous chloride to be equally valuable.

We thus succeeded in stopping the action of the disinfectant upon its arrival in the second flask, and by employing large dilutions further reduced the possibility of the contamination of the culture medium with an antiseptic salt. It will be noticed, also, in examining the detailed history of the experiments, that through planting a control from the second flask *directly* into a large amount of bouillon we checked our final results and escaped the danger of losing the germs through too great dilutions.

In all experiments controls were made into bouillon to determine the initial sterility of the dilution flask; a sample was also planted from the precipitating flask to make sure that the bacteria were not lost in passing from the precipitating or inhibition flask to the third or dilution flask; and finally, controls were made to discover how many bacteria would have appeared in a cubic centimeter of the third flask had the disinfectant been water. We have thus had a constant check on all results, and feel confident that error has as far as possible been eliminated.

In order, however, to guard against all possible error, when the end

of the experiment was reached and the limit of the resistance of the bacterium had been determined by means of the precipitation methods, two other methods were used in order to check the results. One of these was that recommended by Sternberg, namely, exposing the culture to the germicide for a certain length of time and then transferring a small quantity of the mixture — as much as would cling to a platinum needle — into a flask of bouillon and allowing the latter to grow at optimum temperature. The other method was to transfer a platinum loopful of the mixed liquid culture and germicide to a weak solution of ammonium sulphide and then pour the whole of this into a large flask of bouillon. In the latter method we escaped both the difficulty of introducing the corrosive sublimate into the culture and the danger of great dilutions.

The precise method of procedure[1] was this: Bouillon cultures of the species to be tested were grown for two days in the incubator at 37.5°C. Two cubic centimeters of such a culture, after prolonged shaking, and after microscopical and macroscopical examination had determined that it was in good condition, were transferred to a 60 cc. sterile Erlenmeyer flask, and to them 13 cc. of sterile distilled water were added. An equal volume, or 15 cc., of the germicide was next added, and the time of exposure was determined by means of a stop watch. The flask here used may be called the *action flask*, and the time of exposure the *action period*. Towards the end of the action period one cubic centimeter was rapidly transferred to 500 cc. of dilute solution of ammonium sulphide, or stannous chloride, and well shaken for thirty seconds, the precipitate not being allowed to settle. At the end of the thirty seconds one cubic centimeter from this flask, which may be called the *inhibition flask*, was transferred to a flask containing 250 cc. of sterile distilled water; the last flask may be called the *dilution flask*. Immediately after this two flasks, containing each 25 cc. of bouillon, were planted, each with .3 cc., from the inhibition flask. This was done in order to have a dilution control. At the end of a couple of minutes two or three tubes of melted agar were sown with one cubic centimeter each from the mixture in the third or dilution flask, and immediately plated. All plates and flasks were then placed in the incubator at 37.5°C.

Immediately preceding the experiment one cubic centimeter of

[1] In formulating a definite mode of procedure we were guided, in part, by experiments made in this laboratory upon peroxide of hydrogen by the late George V. McLauthlin.

water from the dilution flask was planted in bouillon in order to determine its sterility. This precaution was found to be necessary when working with the spores of *B. subtilis* and *B. anthracis*, both of which proved to be very resistant to ordinary sterilization methods.

Immediately following each series of experiments a control experiment was made as follows: Two cubic centimeters of the bouillon culture used in testing were diluted with 28 cc. of water, and one cubic centimeter of this diluted culture carried into 500 cc. of ammonium sulphide in the inhibition flask. After thirty seconds one cubic centimeter from the mixture in the inhibition flask was carried to the dilution flask, containing 250 cc. of sterile water, and from the last flask agar plates were made by sowing in each tube of melted agar one cubic centimeter of the liquid and then plating the mass. Two other controls were obtained for each species by substituting for ammonium sulphide in the inhibition flask stannous chloride in the one case and distilled water in the other, and making the dilutions the same as in the principal testing experiments.

This routine was repeated for the different action periods until it was found that the germs were killed. When this knowledge had been obtained still another control was employed, namely, Sternberg's method and the modification of it already described.

It will thus appear that all results obtained were carefully checked, and all tests finally made in duplicate or triplicate. After the actual theoretical value of the germicide had been thus established, its actual value in practice was proved by its action on a typhoid fever stool.

A DETAILED ACCOUNT OF THE EXPERIMENTS MADE TO DETERMINE THE GERMICIDAL EFFICIENCY OF THE DISINFECTANT.

A. Experiments upon the Typhoid Fever Bacillus of Eberth.

Inasmuch as the tests with this bacillus were the first undertaken, it was necessary to develop the methods to be used in testing. The first few experiments were therefore intended to determine whether the stannous chloride or the ammonium sulphide were objectionable because of being germicides in themselves, and whether either method was superior to that of simple dilution in water.

Experiment 1, when compared with Experiment 2, indicated that the method of inhibition by precipitating with stannous chloride, was superior to that of diluting with water. Experiment 1, in which the

chloride was used, indicated that the germs were still alive after one minute's exposure, while Experiment 2 showed that all had been killed. If, then, we had relied upon the method of simple dilution we should have been led into error at the start.

EXPERIMENT 1.

1 volume of disinfectant diluted with 3 volumes of water.

1 cc. of 50-days-old bouillon culture of Eberth bacilli introduced into 250 cc. of this diluted disinfectant and exposed for one minute.

1 cc. of the mixture of disinfectant and culture then carried to 500 cc. of dilute, weakly acid stannous chloride, and left for 35 seconds.

1 cc. of liquid from the stannous chloride flask then mixed with 500 cc. of water and well shaken.

From the last flask five agar plates were planted with one cc. each.

Result: Average number of colonies per cc. of last flask, 3.

EXPERIMENT 2.

Same conditions as in preceding experiment. Disinfectant same strength and in same amount, and the same amount of the same culture used.

Exposure to the disinfectant, one minute.

1 cc. of mixture of culture and disinfectant then. carried to 500 cc. of sterile water and well shaken for 35 seconds.

1 cc. of this fluid then carried to 500 cc. of sterile water.

Five agar plates were planted with 1 cc. of the last flask.

Result: All the plates were sterile.

These experiments having indicated the value of the stannous chloride as an inhibitor, we next proceeded to determine that of the ammonium sulphide.

EXPERIMENT 3.

2½-days-old bouillon culture of Eberth bacilli. Grown at 37.5°C.

1 cc. of this culture carried to 250 cc. of disinfectant diluted as in 1 and 2. Exposed 20 seconds.

1 cc. of the disinfectant and culture then mixed wtth 500 cc. of ammonium sulphide. Exposed for 20 seconds.

1 cc. of this mixture from Flask 2 well washed in 500 cc. of sterile water.

Five agar plates were then made from the last flask, each plate containing 1 cc.

Result: Three plates were sterile; two had one colony each upon them.

In order to determine whether a longer exposure to the ammonium sulphide would injure the bacteria we allowed the inhibition flask to stand for three minutes, when we again diluted one cubic centimeter of it with 500 cc. of sterile water, and after shaking planted five cubic centimeters of the last dilution in five tubes of agar.

Result: Two of the plates had one colony each; one of them contained three; and the third was sterile.

This indicated that the sulphide possessed a very slight action upon the bacteria, if it exerted any at all. The slightly greater numbers of bacteria grown on these plates were wholly within the

range of variation in exactly similar series of experiments. Otherwise they would seem to indicate that a longer exposure of the bacteria to the sulphide was advantageous.

The next experiment was made to test the value of washing the disinfectant from the bacteria by water.

EXPERIMENT 4.

Same conditions and culture as in Experiment 3, but the exposure was for 18 seconds.

1 cc. of mixture of disinfectant and culture was well shaken in 500 cc. of sterile water for 20 seconds, Flask 2.

1 cc. from Flask 2 then shaken in 500 cc. of sterile water, Flask 3.

Six agar plates were planted with 1 cc. each from Flask 3.

Result: three plates sterile; two plates had one colony each upon them.

The result of this experiment would seem to indicate that simple dilution was as effective as ammonium sulphide precipitation. Further experiment proved that this conclusion was erroneous. Experiment 5 is the control for the two preceding, made in order to determine whether the bacteria had been lost by too great dilution.

EXPERIMENT 5.

1 cc. of same culture as in Experiment 4 diluted with sterile water to the same degree that it would have been diluted had it passed through the action, inhibition, and dilution flasks. No disinfectant used.

Six agar plates planted with 1 cc. each of Flask 3.

Result: These plates had an average of eleven colonies each upon them.

The result of Experiment 5 was sufficient to convince us that the dilution of the disinfectant was too great; and thereafter, with the exception of the next control experiment, we reduced the last flask to 250 cc.; reduced the disinfectant volume to 15 cc.; and employed two cc. of the culture in the place of one.

EXPERIMENT 6.

This was made to test the germicidal power of the stannous chloride.

1 cc. of culture was carried to 250 cc. of sterile water.

1 cc. of this mixture then planted in 500 cc. of dilute stannous chloride and left for 20 seconds.

1 cc. of this then carried to 500 cc. of sterile water.

Six agar plates were planted each with 1 cc. of last flask.

Result: There was an average number of 14 colonies upon each plate.

This result proved that the stannous chloride in the length of time the bacteria was exposed to it, and in the strength in which it was used, exerted no appreciable deleterious effect upon the typhoid bacilli.

Having now made a test of methods, in which it appeared that there was little advantage in using stannous chloride in preference to ammonium sulphide as inhibitor, we proceeded to determine the efficiency of the disinfectant. For this purpose we employed the disinfectant diluted to twice its normal bulk. This dilution was secured in the early experiments by means of the culture fluid itself. Later, however, we diluted with water. This strength of the disinfectant was adopted as the standard both because it seemed likely that such a strength would be the one employed in practice and because we were thereby enabled to compare its efficiency with that of neutral solutions of mercuric chloride of the strength 1 : 1,000 as determined by many experimenters.

EXPERIMENT 7.

Fifteen cc. of a two-days culture in bouillon of Eberth bacilli were mixed with 15 cc. of disinfectant full strength. Thus the culture acted as the diluter of the disinfectant. The exposure was for 25 seconds.

1 cc. of the mixture was then carried to 500 cc. of stannous chloride and shaken for 20 seconds.

1 cc. from this flask was then transferred to Flask 3, containing 250 cc. of sterile water.

Five agar plates were then planted from the last flask with one cc. each.

Result: All the plates were sterile.

EXPERIMENT 8.

Identical with the preceding, except that the culture was exposed to the disinfectant for 45 seconds.

Five agar plates planted from the last flask.

Result: All plates sterile.

EXPERIMENT 9.

Control of 7 and 8.

½ cc. of culture transferred to 500 cc. of stannous chloride for 20 seconds.

1 cc. of this fluid then diluted with 250 cc. of sterile water.

Two agar plates planted with 1 cc. each from the last flask.

Result: 2,035 colonies upon each plate.

It was obvious from the preceding experiments that twenty-five seconds' exposure sufficed to kill the bacteria. We now determined the minimum length of time of exposure necessary to accomplish this result. Here we adopted a slightly different method of pro-

cedure. It will be observed that the disinfectant was diluted in these cases with the culture medium itself. Considering that this medium was of an albuminous nature and therefore likely to introduce an element of uncertainty into the results, as the exact solubility of the albuminate of mercury is a matter of dispute, and its effect upon the germicidal value of mercuric salts has also been questioned, we freed the bacteria from this albuminous envelope as far as possible by thoroughly shaking two cubic centimeters of the culture in sterile water sufficient to dilute the disinfectant to twice its bulk. Hereafter, then, it will be understood that the 15 cc. of disinfectant were diluted with 13 cc. of water and 2 cc. of culture medium. In this way the bacteria themselves were exposed more directly to the action of the germicide.

EXPERIMENT 10.

Fifteen cc. of disinfectant mixed with 13 cc. of water and 2 cc. of culture of typhoid bacilli. Exposure of 10 seconds.

1 cc. of mixture carried to 500 cc. of stannous chloride for 20 seconds.

1 cc. from this flask, known as the inhibition flask, next transferred to a dilution flask containing 250 cc. of sterile water.

Two bouillon flasks containing 25 cc. each of bouillon were then sown with 0.2 cc. each from the inhibition flask (No. 2).

Two agar plates were made from Flask 3.

Result: One bouillon flask sterile; other bouillon flask growth. Agar plates, two sterile; the third contained two colonies.

EXPERIMENT 11.

Identical with 10, except that the exposure to the disinfectant was for 15 seconds.
Agar plates and bouillon flasks planted as in the preceding experiment.
Result: both plates sterile. Both bouillon flasks sterile.

EXPERIMENT 12.

Identical with 10, except that the exposure to the disinfectant was for 20 seconds.
Agar plates and bouillon flasks planted as in 10.
Result: Agar plates were sterile. Bouillon flasks were sterile.

From these experiments it follows that the Eberth bacillus of typhoid fever is killed by an exposure to the disinfectant — the latter being diluted to one half its original strength — of about twelve seconds. It is not killed in ten seconds, but it is in fifteen. We now proceeded to control this result by inhibition with ammonium sulphide in the place of the stannous chloride.

EXPERIMENT 13.

Identical with 11, except that ammonium sulphide was placed in the middle flask in place of the stannous chloride. The culture was the same and the dilutions were to the same amount and of the same kind.

Exposure of culture to the disinfectant for 15 seconds. Carried to the sulphide and exposed for 30 seconds.

Agar plates made from Flask 3, and bouillon flasks from Flask 2.

Result: Agar plates sterile. Bouillon flasks remained sterile.

EXPERIMENT 14.

This experiment the same in all respects as 13, except that the exposure to the disinfectant was for 10 seconds only.

Result: Bouillon flasks sterile; agar plates sterile.

It will be seen that the inhibition with ammonium sulphide confirmed the results of inhibition with stannous chloride. The only difference was that the latter method showed some of the bacteria to be still alive after ten seconds' exposure to the disinfectant, while the former indicated that all had been killed. It may have been that in the former case the exposure was for a second or two longer than in the latter, as it was impossible to work with an accuracy within a second.

The control experiments for the above, to guard that the bacteria should not be lost from too great dilution, showed the last flask to contain 150 colonies to the cubic centimeter, and proved the dilutions to be safe. We also made another control, to determine that the stannous choride was harmless. The plates showed an average of 104 colonies to the cubic centimeter — a result within the range of unavoidable differences in the number of bacteria transferred from flask to flask.

The result was then tested by Sternberg's method as follows:

1 cc. of culture was introduced into 1 cc. of disinfectant. At the end of 10 seconds a little of the mixture was carried on a platinum needle and mixed with 25 cc. of bouillon. The flask remained sterile after being in the incubator for three days. At the end of 15 seconds another flask was sown in the same manner. This flask also remained sterile.

A further confirmation was secured in the following way:

1 cc. of culture was introduced into 1 cc. of disinfectant. At the end of 10 seconds a platinum loop of the mixture was mixed with 1 cc. of dilute ammonium sulphide, and after 30 seconds here the mixture was poured into a flask of bouillon containing 25 cc. The bouillon flask at the end of 24 hours contained a fine crop of typhoid bacilli. At the end of 15 seconds exposure to the disinfectant a second platinum loop of the mixture was precipitated in the same manner and sown in bouillon. This flask remained sterile.

Conclusion: The typhoid fever bacillus of Eberth is killed by an exposure of 15 seconds to the disinfectant when the latter is diluted to twice its bulk.

B. Experiments upon Spores of Bacillus Subtilis.

In all experiments upon *Bacillus subtilis* we employed a bouillon culture grown for three days at 37.5° C. and microscopically determined to be in the spore state.

EXPERIMENT 15.

2 cc. of culture of *B. subtilis* mixed well with 13 cc. of sterile water. 15 cc. of disinfectant then poured into this. Shaken well for 5 minutes.

1 cc. carried to 500 cc. of ammonium sulphide. Left here for 30 seconds. 1 cc. from Flask 2 then carried to Flask 3, containing 250 cc. of sterile water.

Bouillon flasks were sown from Flask 2, and agar plates from Flask 3.

Result: Growth in bouillon flasks. Agar plates contained an average of 5 colonies.

EXPERIMENT 16.

Identical with Experiment 15, except that stannous chloride was employed as inhibitor. Exposure to disinfectant of 5 minutes. Bouillon flasks and agar plates as usual.

Result: Growth in bouillon flasks. Agar plates had an average of 7 colonies each.

EXPERIMENT 17.

Identical with 15. Ammonium sulphide, inhibitor. Exposure of 7 minutes to disinfectant. Agar plates from Flask 3, bouillon flasks from Flask 2.

Result: Bouillon showed a copious growth. Agar plates an average of 8 colonies.

EXPERIMENT 18.

Same culture as preceding. Stannous chloride, inhibitor. Exposure to disinfectant for 7 minutes.

Result: Growth in bouillon flasks. Agar plates an average of 6 colonies.

EXPERIMENT 19.

Identical with 17, except that exposure was for 10 minutes. Ammonium sulphide, inhibitor.

Result: Growth in bouillon flasks. Agar plates an average of 3 colonies.

EXPERIMENT 20.

Identical with 18, except exposure of 10 minutes. Stannous chloride, inhibitor.

Result: Growth in bouillon flasks. Agar plates an average of 3 colonies.

EXPERIMENT 21.

Control for experiments from 15–20.

2 cc. of culture. 28 cc. of water.

1 cc. of this then diluted with 500 cc. Ammonium sulphide.

1 cc. of mixture then carried to 250 cc. water.

Result: Agar plates showed an average of 12 colonies.

EXPERIMENT 22.

Identical with 17. Exposure for 12½ minutes. Inhibitor, ammonium sulphide

Result: Growth in bouillon flasks. Agar plates sterile.

EXPERIMENT 23.

Same as preceding. Exposure of 15 minutes. Inhibitor, ammonium sulphide.
Result: Bouillon flasks sterile. Agar plates sterile.

EXPERIMENT 24.

Control for 22 and 23.
2 cc. culture. 28 cc. water.
1 cc. of mixture carried to 500 cc. Ammonium sulphide.
1 cc. of this to 250 cc. water.
Result: Agar plates an average of 44 colonies.

It having appeared from the above that *B. subtilis* spores are destroyed in fifteen minutes the result was confirmed by Sternberg's method. The results were as follows:

Flask 1. Exposed 15 minutes showed a growth.
Flask 2. Exposed 17 minutes remained sterile.

We also employed the modification of this method already noticed. The results of this were as follows:

Flask 1. Exposed 15½ minutes and inhibited with ammonium sulphide. Growth.
Flask 2. Exposed 17½ minutes and inhibited with ammonium sulphide. Growth.
Flask 3. Exposed 20 minutes and inhibited with ammonium sulphide. Sterile.
Conclusion: *Bacillus subtilis* spores are, under certain conditions, killed by the germicide diluted to twice its bulk in 20 minutes. Under other conditions they appear to be killed in 17 minutes.

C. Experiments upon the Streptococcus of pseudo-Diphtheria.

This *Streptococcus* has been repeatedly isolated from the membrane in the throats of patients sick with scarlet fever, and others erroneously supposed to have true diphtheria. It apparently bears an ætiological significance in the cases of such membranous inflammations of the throat. It has already been established at this laboratory that this *Streptococcus*, believed by some to be identical with *Streptococcus pyogenes*, is even more resistant to germicides than the bacillus of true diphtheria, *i.e.*, the bacillus of Klebs-Löffler.

EXPERIMENT 25.

2 cc. culture, 13 cc. water, and 15 cc. of disinfectant, mixed for 10 seconds.
1 cc. of the mixture then mixed with 500 cc. of ammonium sulphide for 30 seconds.
1 cc. of this mixture transferred to Flask 3, containing 250 cc. water. Bouillon flasks planted from Flask 2. Agar plates with 1 cc. each from Flask 3.
Result: Agar plates sterile. Bouillon showed a growth.

EXPERIMENT 26.

Same as 25, except the exposure of 12 seconds. Ammonium sulphide.
Result: Agar plates sterile; bouillon flasks sterile.

EXPERIMENT 27.

Control of 25 and 26.
2 cc. of culture mixed with 28 cc. of water.
1 cc. of mixture to 500 cc. of ammonium sulphide for 30 seconds.
1 cc. of sulphide flask then transferred to 250 cc. of water.
Agar plates from Flask 3.
Result: Plates showed an average of 39 colonies.

From the above it appeared certain that an exposure for twelve seconds to the disinfectant when the latter is diluted to twice its volume is sufficient to kill the *Streptococcus diphtheriæ*.

This result was confirmed by Sternberg's method and the modification thereof employed in the case of *B. subtilis* and the Eberth bacillus.

D. Experiments upon Staphylococcus pyogenes aureus.

The culture for these experiments came originally from the laboratory of Dr. Councilman. Three-days-old bouillon cultures were used.

EXPERIMENT 28.

2 cc. bouillon culture, 13 cc. water, and 15 cc. disinfectant. Exposed 10 seconds.
1 cc. of mixture then carried to Flask 2, containing 500 cc. Ammonium sulphide. Exposed here for 30 seconds.
1 cc. then transferred from Flask 2 to Flask 3, containing 250 cc. sterile water.
Bouillon flasks containing 25 cc. bouillon were planted with .2 cc. of mixture from Flask 2. Agar plates with 1 cc. each from Flask 3.
Result: Agar plates sterile. Bouillon flasks sterile.

EXPERIMENT 29.

Same as above, but exposed to disinfectant for 20 seconds. Ammonium sulphide as inhibitor.
Result: Agar plates sterile. Bouillon flasks sterile.

EXPERIMENT 30.

Control for 28 and 29.
2 cc. culture mixed with 28 cc. water.
1 cc. then to 500 cc. ammonium sulphide.
1 cc. of this then diluted 250 times with water.
Result: Agar plates from last flask showed 530 colonies each.

The conclusion from these experiments is that *Staphylococcus pyogenes aureus* is killed by a ten seconds' exposure to the germicide when the latter is diluted to twice its bulk.

This result was confirmed by Sternberg's method and the modification of it already described. In each case the flasks of ten seconds remained sterile, as did also those exposed for twelve and a half seconds.

E. Experiments upon the Spirillum of Asiatic Cholera.

For these experiments we used a bouillon culture grown for four days at 37.5° C. The culture came originally from Dr. Dunham's laboratory.

EXPERIMENT 31.

2 cc. of culture, 15 cc. of disinfectant, and 13 cc. of sterile water were mixed for 10 seconds.
1 cc. of mixture precipitated in 500 cc. Ammonium sulphide. 30 seconds.
1 cc. of this flask then carried to 250 cc. of sterile water.
Bouillon flasks were planted from Flask 2. Agar plates from Flask 3.
Results: Agar plates sterile. Flasks sterile.

EXPERIMENT 32.

Same as 31, except the exposure to the disinfectant was for 15 seconds.
Result: Agar plates sterile. Bouillon flasks sterile.

EXPERIMENT 33.

Control for 31 and 32.
2 cc. of culture diluted with 28 cc. water, then 1 cc. passed through same amounts of ammonium sulphide and water as usual.
Agar plates were planted from Flask 3.
Result: Agar plates showed an average of 5 colonies to a cubic centimeter of liquid from last flask.

The dilutions here were evidently a little too great, but when it is remembered that on this basis the middle flask should contain 1,250 cholera bacilli to the cubic centimeter, if they had not been killed, we considered the fact of the sterility of the flasks of bouillon planted from this flask as evidence enough that the bacteria were killed by the exposure given them.

The experiments upon the *Spirillum* of Asiatic cholera would indicate that this bacterium is killed by an exposure to the germicide diluted to twice its volume for the space of ten seconds.

This result was confirmed by Sternberg's method and the modification of it described. Bouillon flasks at 10 seconds remained sterile.

F. Experiments upon Spores of Bacillus anthracis.

The culture of *Bacillus anthracis* used in these tests was from a luxuriant culture isolated by Prof. G. R. Tucker from a patient in the Boston City Hospital about one year before. A three-days' bouillon culture was used.

EXPERIMENT 34.

2 cc. of culture well shaken in 13 cc. of water; 15 cc. of disinfectant mixed with it for 15 minutes.

1 cc. of the mixture was then inhibited by 500 cc. of ammonium sulphide.

1 cc. from the last flask was, at the end of 30 seconds, carried to Flask 3, containing 250 cc. of distilled water.

Agar plates made from the last flask. Bouillon flasks planted from the inhibition flask.

Result: Agar plates had an average of 3 colonies each. Bouillon flasks showed copious growth.

EXPERIMENT 35.

Control for 34.

2 cc. of culture mixed with 28 cc. of water.

1 cc. of mixture then transferred to 500 cc. of ammonium sulphide for 30 seconds.

1 cc. of mixture then diluted in 250 cc. of sterile water.

Agar plates from last flask.

Result: Plates contained an average of 52 colonies each.

We next passed on to determine the vitality of the spores and found them exceedingly resistant to heat.

EXPERIMENT 36.

1 cc. of the culture used in the preceding two experiments was placed in a sterile test tube and immersed in boiling water. Every two minutes a sterile platinum needle was plunged into the hot culture and then mixed with 6 cc. of sterile bouillon. In order to determine the exact degree of heat to which the spores were exposed we placed next to the tube containing the culture a second tube containing 1 cc. of sterile water, and within this tube suspended a thermometer so that it was at every point separated from the glass of the tube. This thermometer registered as follows: 5 seconds, 60 degrees C.; 10 seconds, 70 degrees; 15 seconds, 80 degrees; 30 seconds, 92 degrees; 45 seconds, 95 degrees; 60 seconds, 97 degrees; 70 seconds, 99 degrees. It remained at this temperature during the course of the tests.

The result proved that some of the spores were still alive at eleven minutes after immersion. We made no test later than that time.

Experiment 34 indicated that nearly all the spores were killed after fifteen minutes' exposure to the disinfectant.

EXPERIMENT 37.

Identical with 34, except that the exposure was for 20 minutes.

Result: Agar plates sterile. Bouillon flasks sterile.

Having now ascertained that anthrax spores of a very resistant type are killed by the disinfectant in twenty minutes, we confirmed the result as usual, by Sternberg's method, and also by the modification of that method already described.

It will be remembered that in the modification of the method we precipitated a platinum loopful of the mixture of culture and disinfectant in ammonium sulphide before pouring the whole mixture into bouillon.

Result:

1½ minutes . . .	Direct.	Growth.	14 minutes . . .	Direct.	Growth.
3 minutes . . .	Direct.	Growth.	17 minutes . . .	Precipitated.	Growth.
5 minutes . . .	Direct.	Growth.	19 minutes . . .	Direct.	Sterile.
8 minutes . . .	Precipitated.	Growth.	17½ minutes . . .	Precipitated.	Growth.
10 minutes . . .	Direct.	Growth.	19 minutes . . .	Precipitated.	Sterile.
12 minutes . . .	Precipitated.	Growth.			

From this result we may conclude that anthrax spores of this high degree of resistance are killed by an exposure to the disinfectant of nineteen minutes, the disinfectant being diluted to twice its volume.

G. A Practical Test of the Disinfectant.

In order to test the working of the disinfectant in actual use we mixed a stool of a typhoid patient with an equal amount of disinfectant. The stool was diarrhœic, but contained many hard lumps of fæces. The mixture was shaken three or four times during the test. In order to determine at what time the stool became sterile we transferred a small portion upon a platinum loop at the end of thirty seconds, and for every minute's interval thereafter up to twenty minutes, to a tube of melted agar containing perhaps 6 cc. of agar. At the end of twenty-four hours the plates planted at thirty seconds' exposure proved to be well spotted with colonies of bacteria, but far less than the control made at the beginning. From this time on they rapidly diminished until at the end of three minutes and a half there were none apparent, nor did any appear upon the subsequent plates or in the bouillon flasks. The efficiency of the disinfectant with fæcal bacteria was thus established.

SUMMARY OF EXPERIMENTS ON *B. TYPHI ABDOMINALIS.*

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
1.	50 days	½	1 minute	$SnCl_2$	3	. . .	. . .
2.	50 "	½	1 "	H_2O	0	. . .	. . .
3.	2½ "	½	20 seconds	$(NH_4)_2S$	0 and 1	. . .	11
4.	2½ "	½	18 "	H_2O	0 and 1	. . .	11
5.	2½ "	. . .	not exposed	$SnCl_2$	11	. . .	. . .
7.	2 "	½	25 seconds	$SnCl_2$	0	. . .	2035
8.	2 "	½	45 "	$SnCl_2$	0	. . .	2035
10.	2 "	½	10 "	$SnCl_2$	0 and 2	growth.	150
11.	2 "	½	15 "	$SnCl_2$	0	sterile.	150
12.	2 "	½	20 "	$SnCl_2$	0	"	150
13.	2 "	½	15 "	$(NH_4)_2S$	0	"	150
14.	2 "	½	10 "	$(NH_4)_2S$	0	"	150

Control: Sternberg's Method, Flask at 10 seconds, sterile.

Control: Modification of Sternberg's Method, Flask at 10 seconds, growth; 15 seconds, sterile.

SUMMARY OF EXPERIMENTS ON SPORES OF *BACILLUS SUBTILIS.*

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
15.	3 days	½	5 minutes	$(NH_4)_2S$	5	growth	12
16.	3 "	½	5 "	$SnCl_2$	7	"	12
17.	3 "	½	7 "	$(NH_4)_2S$	8	"	12
18.	3 "	½	7 "	$SnCl_2$	6	"	12
19.	3 "	½	10 "	$(NH_4)_2S$	3	"	12
20.	3 "	½	10 "	$SnCl_2$	3	"	12
22.	3 "	½	12½ "	$(NH_4)_2S$	0	"	44
23.	3 "	½	15 "	$(NH_4)_2S$	0	sterile	44

Control: Sternberg's Method, Flask at 15 minutes, growth; 17 minutes, growth.

Control: Sternberg's Method, modified, Flask at 15 minutes, growth; 17 minutes, growth; 20 minutes, sterile.

SUMMARY OF EXPERIMENTS ON *STREPTOCOCCUS DIPHTHERIÆ.*

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
25.	3 days	½	10 seconds	$(NH_4)_2S$	0	growth	39
26.	3 "	½	12 "	$(NH_4)_2S$	0	sterile	39

Control: Sternberg's Method, Flask at 10 seconds, growth; 12 seconds, sterile.
Control: Sternberg's Method, modified, Flask at 10 seconds, growth; 12 seconds, sterile.

SUMMARY OF EXPERIMENTS ON *S. PYOGENES AUREUS.*

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
28.	3 days	½	10 seconds	$(NH_4)_2S$	0	sterile	530
29.	3 "	½	20 "	$(NH_4)_2S$	0	sterile	530

Control: Sternberg's Method, Flask at 10 seconds, sterile; at 12 seconds, sterile.
Control: Sternberg's Method, modified, Flask at 10 seconds, sterile; at 12 seconds, sterile.

SUMMARY OF EXPERIMENTS ON SPIRILLUM OF ASIATIC CHOLERA.

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
31.	4 days	½	10 seconds	$(NH_4)_2S$	0	sterile	5
32.	4 "	½	15 "	$(NH_4)_2S$	0	sterile	5

Control: Sternberg's Method, 10 seconds flask, sterile.
Control: Sternberg's Method, modified, 10 seconds flask, sterile.

SUMMARY OF EXPERIMENTS ON SPORES OF *BACILLUS ANTHRACIS.*

No. of the Experiment.	Age of Culture.	Strength of Disinfectant.	Time of Exposure to Disinfectant.	Precipitant used as Inhibitor.	Colonies on Agar Plates.	Bouillon Flasks.	Number of Colonies on Control.
34.	3 days	½	15 minutes	$(NH_4)_2S$	3	growth	52
37.	3 "	½	20 "	$(NH_4)_2S$	0	sterile	52

Control: Sternberg's Method, Flask at 19 minutes, sterile.
Control: Sternberg's Method, modified, Flask at 17 minutes, growth; 19 minutes, sterile.

CONCLUSIONS.

The foregoing experiments appear to establish the fact that the Standard Disinfectant used by the Pennsylvania Railroad Company will, under favorable circumstances, destroy the germs of typhoid fever, diphtheria, Asiatic cholera, and *Staphylococcus pyogenes aureus* in a few seconds, and the spores of *Bacillus subtilis* and *Bacillus anthracis* in a few minutes. It must, therefore, be regarded as satisfactory and of excellent efficiency.

There is no evidence that the zinc chloride materially contributes to its value as a disinfectant, and however great the value of zinc chloride as a deodorant may be, it is probable that if a portion, or all of this, could be replaced by a still more concentrated solution of corrosive sublimate the disinfectant might be improved. The recent paper of Green (*Zeit. für Hygiene*, etc., 13, 511) suggests that the copper chloride also has some value. Finally, the decidedly acid reaction of the disinfectant as received is, from the germicidal point of view, an advantage.

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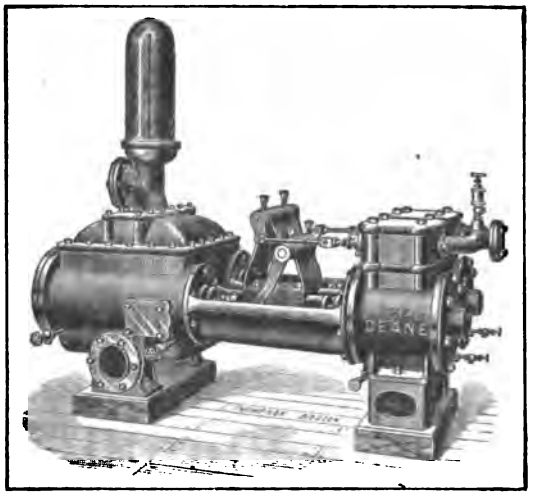

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AND PROCEEDINGS OF THE SOCIETY OF ARTS

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BY-LAWS.

Objects of the Society.

The objects of tne Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement and development in connection with arts, agriculture, manufactures, and commerce.

The Society invites all who have any valuable knowledge of this kind which they are willing to contribute to attend its meetings and become members. Persons having valuable inventions or discoveries which they wish to explain will find a suitable occasion in the Society meetings, subject to regulations hereafter provided; and while the Society will never indorse, by vote or diploma or other official recognition, any invention, discovery, theory, or machine, it will give every facility to those who wish to discuss the principles and intentions of their own machines or inventions, and will endeavor at its meetings, or through properly constituted committees, to show how far any communications made to it are likely to prove of real service to the community.

Section I. — Administration.

The immediate management and control of the affairs of the Society of Arts shall be exercised by an Executive Committee, consisting of the President of the Institute and the Secretary of the Society (who shall be members *ex officiis*), and five other members, who shall be elected by the Society of Arts at each annual meeting, to continue in office until other persons have been chosen in their place.

Sect. II. — Duties of the Executive Committee.

The Executive Committee shall elect its chairman, prescribe his duties, and, with the concurrence of the Treasurer of the Institute, fix his compensation when the interests of the Society require that

he should be paid for his services; they may invite any person to preside at any ordinary meeting who is well versed in the subjects to be discussed; they shall appoint the days and times of meeting, when not fixed by the Society, and determine the subjects to be considered at the meetings and the mode of conducting the discussions; they may, with the concurrence of the President of the Institute, make such arrangements for reporting and publishing the proceedings of the Society as they may deem best suited to advance its interests; they may receive moneys in behalf of the Society in aid of its objects, by subscription, donation, or bequest; they shall make a report of their doings to the Society at its annual meeting and at such other times as a report may be called for by a majority of the members present at any meeting; they shall also make a report of their doings to the President of the Institute prior to the annual meeting, and at such other times as the Corporation may require it. Four members shall constitute a quorum for the transaction of business.

Sect. III. — Duties of the President and Secretary.

1. It shall be the duty of the President of the Institute to preside at the annual and the special meetings of the Society, and also at its ordinary meetings when the Executive Committee does not invite a special chairman to preside.

2. It shall be the duty of the Secretary of the Society to give notice of and attend all meetings of the Society and of the Executive Committee; to keep a record of the business and orders of each meeting, and read the same at the next meeting; to keep a list of the members of the Society, and notify them of their election and of their appointment on committees; and generally to devote his best efforts, under the direction of the Executive Committee, to forwarding the business and advancing the interests of the Society. He shall also record the names of the Executive Committee attending each meeting.

Sect. IV. — Funds of the Society.

All the fees and assessments of members, and all moneys received by subscription, donation, or otherwise, in aid of the Society, shall be paid into the treasury of the Corporation, to be held and used for the objects of the Society under the direction of the Executive Commit-

tee, and shall be subject to the order of its Chairman, countersigned by the President of the Corporation.

Sect. V. — Meetings of the Society.

1. The annual meeting of the Society shall be held at the Institute on the second Thursday in May. The ordinary meetings shall be held semi-monthly, or whenever deemed expedient by the Society or by the Executive Committee, excepting in the months of June, July, August, and September.

2. If from any cause the annual meeting shall not have been duly notified or held as above required, the same shall be notified and held at such time as the Executive Committee may direct.

3. A special meeting of the Society may at any time be called by the Secretary on a written request of ten members. Twelve members of the Society shall constitute a quorum for the transaction of business.

Sect. VI. — Members and Their Election.

1. Members of the Society of Arts shall be of three kinds — Associate, Corresponding, and Honorary Members.

2. Candidates for Associate Membership shall be recommended by not less than two members, whose signatures shall be affixed to a written or printed form to that effect. Each nomination shall be referred to the Executive Committee, and when reported favorably upon by them, and read by the Secretary, may be acted upon at the same meeting; the election shall be conducted by ballot, and affirmative votes to the number of three fourths of the votes cast shall be necessary for an election.

3. Corresponding and Honorary Members may be elected in the same way, on nomination by the Executive Committee.

4. Associate Members shall pay an admission fee of three dollars before being entitled to the privileges of membership, and an annual assessment of three dollars on the first of October of each year, this sum to include subscription to the *Technology Quarterly and Proceedings of the Society of Arts.*

An Associate Member who shall have paid at any one time the sum of fifty dollars, or annual assessments for twenty years, shall become a member for life, and be thereafter exempted from annual assessments.

A member neglecting to pay his annual assessment for six months after being notified that the same is due shall be regarded as having withdrawn his membership, unless otherwise decided by the Executive Committee, which shall be authorized, for cause shown, to remit the assessments for any one year; and which shall moreover be empowered to exempt particular members from assessments whenever their claims and the interests of the Society make it proper to do so.

Sect. VII. — Election of the Executive Committee and of the Secretary.

1. At an ordinary meeting of the Society, preceding the annual meeting, a nominating committee of *five* shall be chosen, whose duty it shall be to nominate candidates for the Executive Committee, to post a list of the names selected in the office of the Secretary, and to furnish printed copies thereof to the members at or before the time of election.

2. At a meeting at which an election is to take place the presiding officer shall appoint a committee to collect and count the votes and report the names and the number of votes for each candidate, whereupon he shall announce the same to the meeting.

3. A majority of the votes cast shall be necessary to an election.

4. In the first organization under these By-Laws, the Executive Committee may be elected at an ordinary or special meeting.

5. Vacancies in the committee occurring during the year may be filled by the Society at an ordinary meeting.

6. The Secretary shall be elected by the Society, on nomination by the Executive Committee, at each annual meeting of the Society, or, in case of a vacancy during the session, at such other time as the Executive Committee may appoint; and he shall be reëligible in the same way at the pleasure of the Society.

7. The compensation of the Secretary shall be fixed from year to year by the Executive Committee with the concurrence of the Treasurer of the Institute.

Sect. VIII. — Committees of Arts.

1. The Members of the Society of Arts may be enrolled in divisions, under the following heads, according to the taste or preference of

the individual; each division to constitute a committee upon the subjects to which it appertains:

(1) On Mineral Materials, Mining, and the Manufacture of Iron, Copper, and other Metals.

(2) On Organic Materials — their culture and preparation.

(3) On Tools and Implements.

(4) On Machinery and Motive Powers.

(5) On Textile Manufactures.

(6) On Manufactures of Wood, Leather, Paper, India Rubber, and Gutta Percha.

(7) On Pottery, Glass, Jewelry, and works in the Precious Metals.

(8) On Chemical Products and Processes.

(9) On Household Economy; including Warming, Illumination, Water-Supply, Drainage, Ventilation, and the Preparation and Preservation of Food.

(10) On Engineering, Architecture, and Ship-building.

(11) On Commerce, Marine Navigation, and Inland Transportation.

(12) On Agriculture and Rural Affairs.

(13) On the Graphic and Fine Arts.

(14) On Ordnance, Firearms, and Military Equipments.

(15) On Physical Apparatus.

2. Any member may belong to more than one of the above-named Committees of Arts, but shall not at the same time be eligible as chairman in more than one.

3. It shall be competent for each Committee of Arts, of ten or more members entitled to vote, to organize; to elect annually in October, or whenever a vacancy shall occur, a chairman; to appoint its own meetings; and to frame its own By-Laws, provided the same do not conflict with the regulations of the Society of Arts.

Sect. IX. — Amendment and Repeal.

1. These By-Laws may be amended or repealed, or other provisions added, by a vote of three fourths of the members present at any regular meeting of the Society; provided that such changes shall have been recommended and approved in accordance with the By-Laws of the Corporation (see extract from By-Laws of Corporation as

printed below) and presented in writing at a preceding meeting of the Society.

2. These By-Laws shall take effect immediately after their approval by the Corporation and adoption by the Society, and all previous By-Laws are hereby repealed.

EXTRACT FROM THE BY-LAWS OF THE CORPORATION.

The Committee on the Society of Arts shall consist of ten members, who shall have the general charge and supervision of the organization and proceedings of the Society, subject to the approval of the Corporation. It shall be their duty, in connection with a duly chosen committee of the same number of members of the Society, to form from time to time By-Laws for the government of the Society, which shall take effect when approved by the Corporation and adopted by the Society.

October, 1893.

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Members are requested to inform the Secretary of any change of address.

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THIRTY-SECOND YEAR, 1893–94.

THURSDAY, October 12, 1893.

THE 448th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. Messrs. Walter B. Snow, of Boston, William A. Johnston and F. A. Wilson, of the Institute, John I. Solomon, of New York, and Edward O. Woodward, of Roxbury, were duly elected Associate Members of the Society.

The amendment to the By-Laws proposed at the previous meeting being before the Society, it was *Voted*, that Paragraph 4 of Section VI of the By-Laws be amended to read as follows: "Associate Members shall pay an admission fee of three dollars before being entitled to the privileges of membership, and an annual assessment of three dollars on the first of October of each year, this sum to include subscription to the *Technology Quarterly and Proceedings of the Society of Arts.*"

The following papers were read by title:

"The Experimental Hydraulic Laboratory of the Massachusetts Institute of Technology," by Dwight Porter.

"Methods Used and Results Obtained in Making Germicidal-

Efficiency Tests of a Disinfectant for Use in Railway Sanitation," by William T. Sedgwick.

"Excursion of the Diaphragm of a Telephone Receiver," by Charles R. Cross and H. M. Phillips.

Professor Gaetano Lanza, of the Institute, then read a paper on "The Educational Process of Training an Engineer," which is published in full in the present number of the *Quarterly.* The paper was followed by a discussion, and the meeting adjourned.

WEDNESDAY, October 25, 1893.

The 449th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. The following papers were read by title:

"Nativity and Occupations of the Members of the Massachusetts Legislature," by F. H. Howland and D. R. Dewey.

"Metallurgical Lead Exhibits at the Columbian Exposition," by H. O. Hofman.

The President then introduced Prof. George E. Hale, of the University of Chicago, who read a paper on "Some Recent Photographic Investigations of the Sun," illustrated by the lantern. It will be published in the next number of the *Quarterly.* After the discussion the President extended the thanks of the Society to Professor Hale for his very interesting paper, and declared the meeting adjourned.

CLEMENT W. ANDREWS, *Secretary.*

THE EDUCATIONAL PROCESS OF TRAINING AN ENGINEER.[1]

By GAETANO LANZA, S.B.

Read October 12, 1893.

In order that I may be able to do justice to the main portion of my subject in the time at my disposal, I shall begin by laying down a few fundamental propositions without stopping to prove them:

1. In order to impart to any individual the best mental training, and hence the best education, the course to be pursued should depend upon his natural aptitude.

2. The study of science as applied to the industrial work of the world, as well as scientific study in general, is fully capable of giving the very best mental training to those whose aptitude lies in that direction.

3. The development of the technological schools of the country during the last twenty-five years has been phenomenal, whether we consider the number of the schools, the number of the pupils, or the character of the courses of instruction and the facilities offered for scientific and industrial education.

4. Any engineering course should aim to fit the student to become an engineer in the best and most thorough manner, and it is mainly on the scientific and practical work of the course that reliance should be placed to impart mental power and hence mental training.

5. The training of the hand and eye should form an important factor in all education, and especially in a scientific and technical education.

6. The recognition of the foregoing statement has led to the introduction of laboratory work in chemistry and in physics, of laboratory and fieldwork in natural history, of manual training in the use

[1] Read also at the Congress of Education (National Educational Association), Chicago, 1893. The course of lectures from which this paper was prepared will be published in the Journal of the Franklin Institute.

of tools, and finally of laboratory work on a practical scale in the various kinds of engineering.

If we analyze carefully the work to be done in the different kinds of engineering — commonly known as civil engineering, mechanical engineering, mining and metallurgical engineering, electrical engineering, and chemical engineering — and perhaps some other industrial pursuits which are not usually called engineering, we shall find in many of them, and I might almost say in all, first, that there are certain processes to be carried out, and second, that attention must be given to devising and preparing the means of carrying out these processes efficiently and cheaply; to the best machines to be used for all the steps in the process, including a consideration of their efficiency, durability, first cost, the expenses necessary for attendance, also for their maintenance and repair, etc.; to the construction and arrangement of the power plant, whether water or steam is used; to the system of transmission, the design and construction of the buildings adapted for the work, including foundations, water supply, drainage, heating and ventilation, light, lighting, fire protection, and a large number of questions of a similar character, all of which are generally recognized as engineering questions. Hence the mining, the metallurgical, the electrical, or the chemical engineer must be primarily an engineer, but he must also be sufficiently versed in the special mining, metallurgical, electrical, or chemical processes to be able to adapt his engineering work to their needs.

When we come to the terms civil engineering and mechanical engineering, which have both been used in different senses at different times, it is impossible to draw a line of distinction and to assert that any one set of engineering operations belongs exclusively to the civil or to the mechanical engineering profession. There are two things which are absolutely necessary for a successful engineer: first, a knowledge of scientific principles and of the experience of the past, and second, his own experience. The latter cannot be imparted in a school, and each man must acquire it for himself subsequently.

The first, therefore, and the most important thing to be done for the student is to give him a thorough drill in the scientific principles which find their application in his profession; for these are the things that should be acquired in school, since it is only with very great difficulty that they can be mastered after the young man begins practice, and it is a decided mistake to neglect this part of his training

in order to impart to him greater skill in such processes as will probably engage his attention the first year after he goes to work.

The two fundamental sciences upon which the scientific principles of engineering are especially dependent are mathematics and physics.

The function of mathematics is to draw necessary conclusions from the assumed data. Mathematics has nothing to do with the correctness or incorrectness of the data. No natural law can be discovered by mathematics alone; the discovery or proof of natural law requires experiment and observation in all cases.

The engineer should have a thorough working knowledge of whatever portions of pure mathematics he needs, to make the calculations that are liable to arise in his work, and also to draw the necessary conclusions which concern the engineering and scientific subjects with which he must deal in his profession; and this latter is all-important, for, if our prospective engineer is to be fit to assume responsibility at some time during his career, then, before he allows himself to use any formula in practice, he ought to know just how it is derived and what are the assumptions that were made in deducing it, as well as the experimental basis upon which rest the constants which he uses in his calculations. Moreover, the world is rapidly waking up to this fact, so that important engineering work is less and less trusted to rule of thumb engineers.

Now, we may say that arithmetic, algebra, geometry, trigonometry, analytic geometry, descriptive geometry, and the differential and integral calculus are absolutely necessary for our prospective engineer, and differential equations are very desirable.

The student should acquire the ability to use his mathematics as a tool, not only for making computations, but also for drawing necessary conclusions of the kinds that apply to his engineering work, and this last is the feature that is most frequently lacking in the mathematical instruction given to engineering students; in other words, the thinking and reasoning faculties of the student should be carefully trained by his mathematics.

The other fundamental science which I have mentioned is physics. Practically, a course in physics is the suitable preparation for a proper understanding of the scientific principles of most of the engineering work with which the student will come in contact. It is clear, therefore, that there is no portion of the work usually dealt with in the best and most thorough courses of general physics but what ought

to be included in the course of our prospective engineer. Also, a certain amount of work in the physical laboratory is of great importance for the student, since it teaches him how to ask questions of nature and how to obtain correct answers; in other words, how to make careful and accurate experiments.

Next, as to chemistry, I cannot claim for it a position of fundamental importance in the engineering part of an engineering course similar to that which belongs to mathematics and physics; nevertheless, a certain amount of chemical knowledge is of great importance to all engineers; but when this amount has been acquired, although a farther knowledge would be useful, it is not one of the most important things. Chemistry, however, when given in the freshman year, fulfills another important function, viz., it introduces the student at the very threshold of his course to scientific work of a character that obliges him to think, and to do this in a direction in which, as a rule, he has not been trained in the preparatory schools; and especially is this true of the laboratory work.

Turning next to the subject of drawing, there are two objects to be accomplished: first, the execution, and second, the power to express ideas by means of drawing, and to read the ideas of others which have been expressed by the same means. Of course, a certain amount of time will have to be employed at the outset to teach the use of instruments and the execution. As soon, however, as he begins to do his work with a fair degree of accuracy and neatness, the attempt should be made to teach him the language of drawing, so that he can readily translate ideas into drawing and *vice versa*. Now, the mathematical theory of drawing is descriptive geometry; hence he should at once be taught descriptive geometry thoroughly, so that he may have a firm grasp of this subject; and I do not believe in the method often pursued that confines him to the first angle for a long time, till he becomes so accustomed to that particular one that when a figure is placed somewhere else the problem looks difficult to him. Indeed, in practice all angles are used, but if one is employed more than others it is the third and not the first. Moreover, the student has not acquired a proper grasp of the subject until he is equally at home wherever the figure is placed. Parallel with the classroom work in descriptive geometry he should be required to make correct and accurate drawings of a number of the problems. He should then be taught to make working drawings from measurements of machinery, making all

the detail drawings needed for the shop, and also assembly drawings from the details.

Free-hand drawing and lettering are both very important matters, *i.e.*, free-hand drawing to such an extent as will enable the student to sketch easily and readily any part of a machine or structure; and he should be taught to make, free-hand, at least one style of neat and plain letters and figures. Of course there ought to be for all, if possible, some drill in topographical drawing, and especially for those whose line of work is liable to lead them in this direction.

As to the drawing done in connection with the other work of the students, which would naturally form a very considerable portion of their total drawing, I shall not speak here.

Next comes mechanism, which is, I suppose, the most elementary of the subjects that are commonly considered to constitute the strictly professional work of a mechanical engineer.

After the student has had a systematic study of mechanism it seems to me that he ought to become familiar with the usual machine tools in general use, and, besides this, that he should make a study of some machines involving examples of decidedly complicated mechanism by actually examining and handling them.

Then, again, we have a special class of problems in mechanism which concern machines that furnish power, as the mechanism of the steam engine; but the one portion of the mechanism of the steam engine that requires special attention is the valve gear. Hence the student must have thorough instruction in valve gears and link motions.

The next course of which I shall speak is one which vitally concerns the engineer at every turn, and therefore one in which it is absolutely necessary that he should be very thoroughly drilled. I refer to theoretical and applied mechanics. This term has been used in different senses at different times and in different places, but in the sense in which I shall use it, it includes a general and mathematical discussion of the action of forces upon bodies at rest or in motion, and also a full treatment of the strength and elasticity of the materials used in construction, both from a mathematical and also from an experimental point of view. To speak more in detail, it includes such subjects as the following, viz.: composition and resolution of forces, conditions of equilibrium, determination of

the centers of gravity of lines, of areas, and of solid bodies, the general laws of dynamics; as a treatment of uniform and varying motion, the pendulum, determination of moments of inertia and of centers of percussion, the laws of friction, determination of the work used up in friction, both by mathematical calculation and by actual experiment, etc. Then come the determinations of the stresses in the different members of trusses of all sorts, and then a study of the mathematical discussion of the strength and elasticity of materials, *i. e.*, a study of the distribution of the stresses acting in tension rods, struts or compression pieces, beams or other pieces bearing a transverse load; also in all sorts of pieces that are subjected to shearing, including riveted joints, shafting, and beams, as well as in other pieces; the distribution of the stresses acting in a hook, or in any tension or compression piece that has to bear an eccentric load; the modes of determining the deflections of beams, the angle of twist of shafts, or the amount of yielding of pieces generally under load; theories and modes of calculation of the stresses at different parts of continuous girders, determinations of the stability of, and of the stresses acting in arches which bear a load, whether made of stone or of iron; stability of domes, and a study of the theory of elasticity.

Then turning to the experimental side, the student should be made familiar with what experiments have been made and what results they have shown as regards the strength and the stiffness of such pieces as are used in construction to bear a load.

Moreover, the account of these experiments should be brought up to date, and special emphasis should be laid on the results of those where the conditions of practice as to size, manner of loading, and treatment generally have been exactly or at least approximately copied. Moreover, the man who trusts to formulæ derived from some handbook to make his calculations for the strength of materials, while he does not know the principles upon which those formulæ are based and is unable to deduce his own formulæ, is a dangerous man to be trusted with responsible work, and just as there is no royal road to learning, so there is no means by which formulæ can be substituted for a knowledge of principles.

Turning now to a consideration of the constants to be used, the fact is, that it is only within the last fifteen years that a great deal of activity has been displayed in testing the strength of pieces of

practical size, and under conditions imitating closely those of practice, and that a flood of light has been thrown on the question as to what are and what are not reliable constants to use. Calculations based upon incorrect constants cannot give rise to safe structures and machines.

What I have said is enough to show how very important it is that the study of strength of materials, both the mathematical and experimental portions, should be very thorough and detailed.

The next course to receive our attention is thermodynamics and steam engineering. It might be assumed by some that this was peculiarly the province of the so-called mechanical engineer; but, that it is the province of every engineer of whatever name becomes evident when we consider that steam is the principal source of power, and that without power all the works would have to shut down.

Moreover, the expenses for power in any large concern form a very large item; they comprise the first cost of the power plant, including the necessary buildings, coal bunkers, etc.; the expenses of maintenance and of operation, including coal, water, and attendance; and the expenses for repairs. It behooves the engineer, therefore, to try to make the most economy that he can.

Hence, it is plain that our prospective engineer needs a thorough course in steam engineering, of which thermodynamics is merely the theoretical part. Let us consider how such a course should be laid out, assuming, of course, that the student is already familiar with valve gears and with the mechanism of the steam engine; also assuming that he has had a course of heat in his physics, and that in this course he has been taught thermometry, calorimetry, and the laws of the transference of heat.

He should then be taught the nature and construction of the steam engine indicator, how it is to be used, how the indicator card is taken and what it means, and he should acquire some familiarity with interpreting the characteristic, and also some of the peculiar features of indicator cards; and then he should be made familiar with the general characteristics, *i. e.*, outward characteristics of the different types of steam engines.

Next, he should receive a thorough drill in the principles of thermodynamics. What is thermodynamics, and what kind of a course should our prospective engineer have in the subject? Thermodynamics is simply the mechanical theory of heat, or, in other words,

the science of heat with special reference to the production of motion.

Now, in the course to be given we must include a thorough treatment of the fundamental principles of thermodynamics, Carnot's function, the whole set of fundamental equations and their interpretations. Then come the applications of these fundamental principles to the gases and vapors used in practice for producing power; especially steam, and also gas and air. Then a study of the experiments that have been made, and the results of the experiments upon the properties of vapors and gases, experimental determination of the mechanical equivalent of heat, tables of the properties of saturated steam, as pressure, temperature, density, specific heat, latent heat, entropy, etc.; also the same for other vapors; a study of the laws governing the flow of fluids, both gases and vapors, through orifices and in pipes, including a consideration of the resistances. The steam injector comes next, and then the student is prepared for a study of the behavior of steam in the cylinder of a steam engine. In this connection he should be taught the modern methods of analyzing and separating the various actions of the steam that passes through the engine, and of giving to each its proper consideration, both in the case of single and in that of multiple expansion engines, and, in the case of the latter, the effects of different sizes and arrangements of receivers, the methods of proportioning the cylinders, etc.

Next, he should learn how to make a proper engine test, both when it is for commercial purposes, and also when it is to be made in a thoroughly complete and scientific manner, for the purpose of obtaining definite knowledge as to how to produce the best results by means of a steam engine.

The day of the taking of a few indicator cards from an engine, or the making of tests in which scientific principles and scientific accuracy are not attended to, and claiming that such tests can furnish information as to what are the real effects of different arrangements, is rapidly passing away, the advocates of such a course confounding themselves by reaching too many contradictory conclusions by means of their tests. The student should have presented to him in a carefully systematized form an account of such experiments as have been made, with such degree of accuracy and such regard for scientific principles as to render them worthy of study, and he should

thus become familiar with what is the extent of our knowledge of the subject up to date. He should then have a good course in steam boilers, their characteristics, construction, operation, and accessories, including chimneys, economizers, etc.; but I shall not stop to enter into detail for lack of time.

Parallel with this course of steam engineering in the classroom, the student should be made to begin work in the laboratory by making steam engine tests, alternating his duties at each successive test until he has been drilled in performing all the different parts of the work and in making all the calculations necessary.

Another fundamental subject is hydraulics. Our prospective engineer should study the principles of hydraulics, or the laws governing the pressure of water, and the flow of water in pipes, in open channels, through orifices, and over weirs. He should also become familiar with the character and results of such experiments as have been made upon these subjects, and should know how to conduct such experimental work.

In whatever special line of engineering he is subsequently engaged, he may have to establish a water supply, or a system of sewerage, or the works necessary for a water power plant, or river or harbor works, or at least a dock, a wharf, or a quay, if his works are on the water's edge.

Unless his specialty is to be hydraulic work, he cannot, in his four years' course, study in detail all these things, but he should become familiar in any case with the principles already stated, and then, by means of an option in the course, or after graduation, he can make a special study of a part or all of these subjects if he has occasion to do so.

As to how far electricity ought to be accounted as a fundamental subject, and consequently required of all engineering students whatever their special lines, we may observe that it is customary now to require some electricity in connection with the general physics, any farther study of the subject being reserved for those who take the electrical engineering course. Whether a considerably larger amount should be put in the list of fundamental studies will depend upon how far electrical appliances associate themselves with the every-day work of the engineer, whatever his special line. In my opinion it is probable that in the near future we shall have to insert a much larger amount of electricity in the work required of all engineering students whatever their specialty.

The subjects thus far enumerated are fundamental, and our prospective engineer cannot afford to do without them. We must next consider what other subjects should be added, and they may be classified as follows:

1. Subjects of a professional nature bearing on the work of the engineer in general, whatever his specialty.

2. Subjects of a professional nature bearing on the special line of engineering the course is intended to teach.

3. Subjects of a general character suited to impart general information.

4. Subjects which fulfill partly one of these functions, and partly another.

In the first class I should place machine design, dynamics of machinery, metallurgy of iron, heating and ventilation, stereotomy, surveying, shopwork. How many and which of these subjects can be added will depend upon circumstances,

The course in machine design, to be of the greatest value, should deal especially with the details of machines. Thus the student should be made to study each separate piece and its connection with the other pieces, to determine the forces acting upon it and the stresses to which the piece is subject in consequence of the action of these forces, and to design the separate details in such a manner that they shall have the requisite strength and stiffness, as well as that they shall fulfill in the best way the purposes for which they are made. Hence the designs should be of a sufficiently limited extent to admit of this careful study of details.

Under the term dynamics of machinery I include such subjects as governors, fly-wheels, dynamometers, the action of the reciprocating parts of the steam engine, etc. The mere mention of the names of these subjects will make plain their importance, and the same is true of metallurgy of iron and heating and ventilation; stereotomy is merely a species of advanced descriptive geometry, and can easily be acquired by one familiar with the latter. As to surveying and topographical drawing, of course every engineer ought to know something of them, but the principles of surveying are easily learned by any one having a scientific training and some skill in

handling measuring instruments; and nicety of execution can only be attained by long continued practice, which can be acquired after leaving school.

Next, as to shopwork, it is a matter in which every engineer ought to have some practice, but which should not be allowed to crowd out more important engineering work. Indeed, it would be well if this could be acquired at a manual training school before the student enters the engineering school.

Next, as to the studies of the second class, we may make two subdivisions: first, those requisite for such specialties as can be developed by a suitable addition of certain lines of work, but where these lines of work depend upon the previous training that has been given; and second, those where a considerable knowledge of, and hence a drill in chemistry, is necessary. In the first subdivision I should place bridges, hydraulic engineering, railroad engineering, with special reference to motive power, and rolling stock, marine engineering, mill engineering, naval architecture, electrical engineering (though unless the amount of electricity previously studied has been considerable there will be a tolerably large amount of preliminary work required); and others as they may arise.

In the second subdivision I should place mining, metallurgical and chemical engineering, and others as they may arise. The essential difference between these two subdivisions is that in the latter a certain amount of chemistry becomes one of the essential fundamental studies, and must be so treated in planning the course; though we must bear in mind that these are engineering courses, and are intended to fit men to become engineers and not analytical chemists.

Let us assume that we have fixed upon the fundamental subjects and the time that must be given to each, we are then prepared to map out the course to be pursued in what I have called the second class of studies (not the second subdivision only), *i. e.*, the special line of studies, including any of the first class that it is thought best to insert in the list. Neither the time at my command nor the object I have in view allows me to consider in detail what should be given in the case of each special engineering course in these special lines. I shall, therefore, only mention a few general rules to be observed in making the selection.

1. To drill the student in all the details of his profession, or to impart to him experience, is not possible in a school.

2. To attempt to perfect him in those things that he will have to do when he first goes to work at the expense of his later success is a very short-sighted policy.

3. The work in these special lines should be so laid out as to fit him, as thoroughly as possible, to grapple with the classes of problems that he is likely to meet in the practice of his profession, in a thoroughly scientific manner, and thus to teach him the relations of his scientific study to the practical problems he will meet later in life.

As to the third class of subjects, or those intended for general information, it is desirable to insert as much as is possible without sacrificing the accomplishment of the main objects for which the course exists. Such subjects are mainly linguistic and literary. The first, however, if confined to the modern languages, are also to a certain extent professional, for, without them, some of our most valuable engineering literature would be closed to the student.

There remains for me to speak of the graduating thesis, and the extent to which laboratory practice should enter into the course.

The graduating thesis should be planned solely with reference to the part it will play in imparting instruction of the kinds necessary to prepare the student to make a success in his professional life, in the long run. Its special feature should be investigation, and its chief object to teach the student how to carry on scientific research.

In giving the instruction I have outlined, it should not be merely classroom instruction, but also laboratory work. Of course, the student will also have work in his special laboratories, as in the mining, the electrical, or the industrial chemistry laboratory, etc., besides the regular chemical and physical laboratory work; but we will now confine our attention to what are generally understood by the term engineering laboratories, *i. e.*, those bearing upon the work common to all kinds of engineering, such as laboratories for testing the strength of materials, steam engineering laboratories, hydraulic laboratories, etc., and we may note that the principal objects to be accomplished by them are:

1. To give the students practice in such experimental work as an engineer is liable to be called upon to perform in the practice of his profession.

2. To give them opportunity to carry on original investigation in the engineering line.

3. To carry on systematic investigations of engineering problems, and, by publishing the results from time to time, to add gradually to the common stock of knowledge.

I recognize the incapacity of the student, as a rule, to originate and carry out research without aid from his teachers; but when this aid is given, and the necessary supervision exercised, a considerable amount of research can be accomplished by means of the regular work, and also by means of the thesis work.

The equipment of such laboratories must depend to a great extent upon the means at command; but if the teacher will keep clearly in mind the objects which such a laboratory ought to aim to fulfill, and will exercise good judgment, he can do considerable with moderate means, and more as his means increase. In closing I will say, that the introduction of laboratory work into our engineering courses and the work done by the laboratories have exerted a very great influence towards bringing closer together the engineering courses of the schools and the actual work of the engineer in practice.

ON THE EXCURSION OF THE DIAPHRAGM OF A TELEPHONE RECEIVER.[1]

BY CHARLES R. CROSS AND HENRY M. PHILLIPS.

Received October 6, 1893.

THE present investigation is a continuation of one upon the same subject by Messrs. Cross and Mansfield, the results of which have already been published in the *Quarterly*.[2]

In the study of the excursion of the telephone diaphragm described in the paper referred to, the current employed was an alternating current from a dynamo-electric machine, the magnitude of which current was considerably above that of the telephone currents employed in practice. In the present investigation we have employed the currents furnished by a powerful long-distance microphone transmitter to actuate the receiver, and have measured the amplitude of the vibration of the diaphragm of the receiver under such currents when the strength of the polarizing magnet was varied.

The apparatus employed was substantially identical with that described in the paper referred to. A more sensitive electro-dynamometer with a unifilar suspension was used, and the support holding the disk of the receiving telephone was made somewhat more rigid, as it was found that it yielded slightly under the strong pull of the polarizing magnet when this was strongly magnetized and in close proximity to the diaphragm. The microphone, actuated by a C_8 stopped organ-pipe of large scale, blown by a carefully regulated blast, was placed in the primary circuit of an induction coil, such as is ordinarily employed with the long-distance transmitter. In the secondary circuit was placed the receiving telephone which was to be studied, and also the electro-dynamometer and an adjustable water resistance. In a few experiments the ordinary hand magneto-receiver was used, but in most cases we employed an experimental receiver like that used in the earlier studies referred to. The core was a bar of Norway iron, $\frac{3}{4}$ inch in diameter and 8 inches long, wound with 2,750 turns of

[1] Read at a meeting of the American Academy of Arts and Sciences, Jan. 11, 1893.

[2] *Technology Quarterly*, 6, 69.

No. 18 (B. & S.) insulated copper wire. The current which traversed these coils was furnished by a dynamo machine. The current from the dynamo passed through an incandescent lamp and a variable resistance frame, with which last the magnet was placed in derived circuit. By varying this current any desired strength of field could be obtained. In all our experiments the core of the electro-magnet was far removed from saturation, so that we may assume the strength of its field to have been proportional to the current traversing its coils.

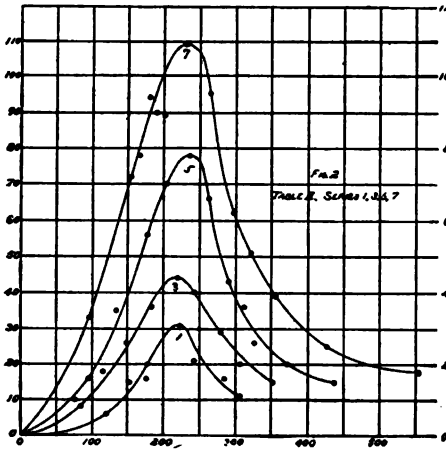


FIG. 2.

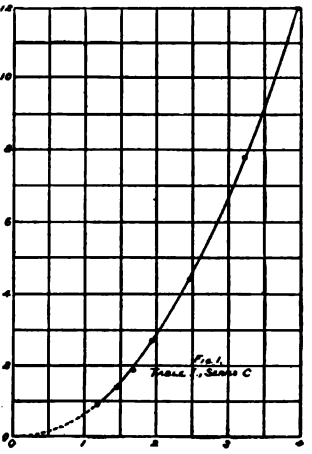


FIG. 1.

The strength of this current was measured in the earlier experiments by a Thomson graded galvanometer, and in the later ones by a Weston milliamperemeter. The transmitter current was furnished by a single storage cell, and the organ-pipe which served as a source of sound was placed in a distant room. The arrangement of the stroboscopic fork was similar to that used in the previous work.

The first measurements were made with an ordinary magneto-telephone as a receiver. The line current was varied, and the corresponding excursion of the diaphragm determined, with the results given in Table I. Series C is graphically illustrated in Figure 1. The values given in the table are the mean of three or more closely concordant readings. In this and the following tables the current is given in milliamperes, the excursion in terms of one micrometer division as a unit. In the figures the abscissas represent currents, and the ordinates excursions.

TABLE I.

Series A.		Series B.		Series C.	
Line Current.	Excursion.	Line Current.	Excursion.	Line Current.	Excursion.
3.94	11.9	3.97	12.3	3.96	12.0
3.06	7.1	3.35	8.5	3.22	7.8
2.52	4.7	3.12	7.4	2.47	4.4
1.96	2.7	2 68	5.3	1.94	2.7
1.49	2.5	2.16	3.4	1.68	1.9
1.21	0.9	1.83	2.4	1.45	1.4
1.06	0.7	1.49	1.5	1.19	0.9
		1.30	1.1		

It appears from these results that, with the magneto-receiver now used, the change in the amplitude of the vibration is approximately proportional to the change in strength of the current for the stronger currents used in the measurements, but with the weaker currents the amplitude increases at a more rapid rate. These currents as a whole, however, are higher than those reached in practice.

In subsequent experiments we used as a receiver the electro-magnetic telephone previously mentioned. The end of its core was set at a distance of $\frac{1}{32}$ inch from the diaphragm. With the undulatory current in the line coil maintained at a constant value in each separate series of experiments, while the magnetizing current was varied, results were obtained as shown in Table II. Line currents with values successively varied in the different series were produced by the microphone transmitter. The values of the magnetizing currents in milliamperes are given in the first column, the corresponding excursions of the diaphragm in terms of one division of the micrometer in the second. Series I, III, V, and VII are represented by the curves in Figure 2.

The results reached agree very well with those obtained by Cross and Mansfield, when currents from an alternating dynamo were used, except that in these last the maximum value of the excursion was reached with a magnetizing current of 320 milliamperes, while with those obtained in the present investigation the maximum value was

reached when the magnetizing current was only 225 milliamperes. This difference arises from the fact that in the earlier experiments the end of the core of the magnet was set at a distance of $\frac{3}{64}$ inch from the diaphragm, while in the present ones it was at a distance of only $\frac{1}{32}$ inch, and so approached saturation sooner.

TABLE II.

SERIES I.

Line Current = 1.25 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
120	6	176	16
178	20	243	21
153	15	285	16
223	31	307	11

SERIES II.

Line Current = 1.5 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
117	14	244	35
150	22	280	23
184	29	301	20
220	36	350	10

SERIES III.

Line Current = 1.9 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
83	8	244	40
115	18	280	29
149	26	306	20
184	36	352	15
220	44	...	...

SERIES IV.

Line Current = 2.2 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
83	9	245	53
119	16	283	37
151	35	308	27
18	45	351	18
223	51	486	10

SERIES V.

Line Current = 2.6 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
75	10	263	66
95	16	291	43
135	35	312	36
178	56	327	26
204	70	372	20
237	78	438	15

SERIES VI.

Line Current = 2.8 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
74	11	287	51
119	31	301	42
160	44	355	25
181	56	327	33
219	75	481	13
249	68	...	...

SERIES VII.

Line Current = 3.37 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
96	33	265	95
190	90	297	62
155	72	322	51
167	78	356	39
181	94	428	25
201	89	554	18
232	109	...	...

Experiments were also made with the same apparatus, in which the strength of the field magnet of the telephone was kept constant by maintaining a constant current in its coils, while the line current was varied. In the first series of these the diaphragm was separated from the end of the core by a distance of $\frac{1}{32}$ inch. The results are given in Table III, and Series VIII, IX, XI, XIII, and XIV are graphically illustrated by the curves of Figure 3.

TABLE III.

SERIES VIII.

Magnetizing Current = 135 milliamperes.

Line Current.	Excursion.
3.15	33
2.76	27
2.05	14

SERIES IX.

Magnetizing Current = 160 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
3.46	73	2.29	32
2.98	56	1.72	23
2.74	46	...	...

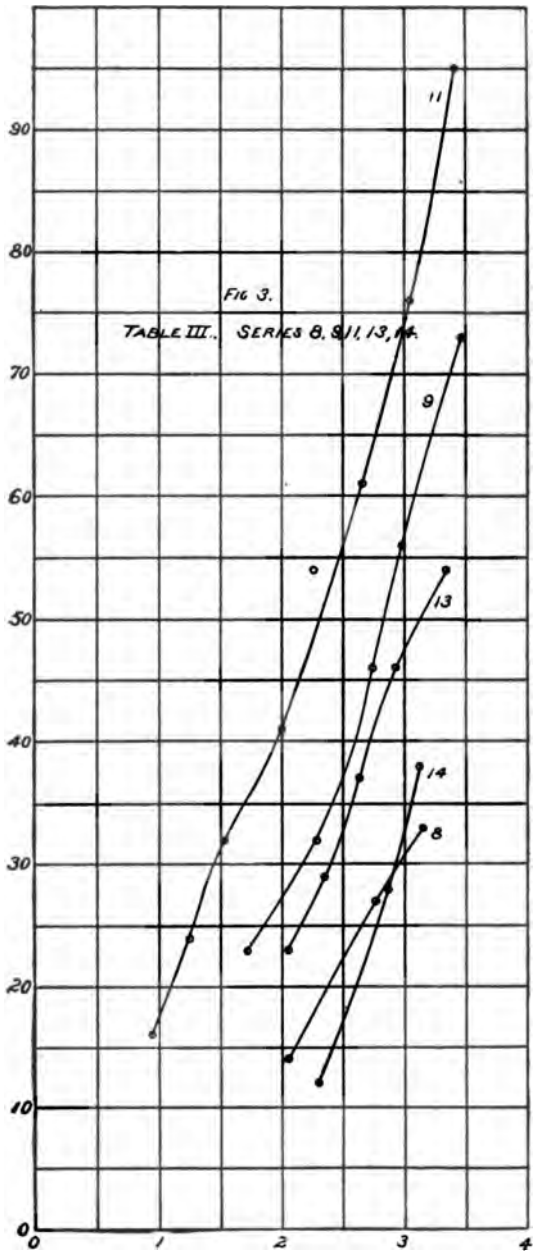


FIG 3.
TABLE III., SERIES 8, 9, 11, 13, 14.
11
9
13
14
8
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4

FIG. 3.

SERIES X.

Magnetizing Current = 190 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
3.49	95	1.91	41
3.00	82	1.45	31
2.82	69	1.25	23
2.24	49	1.12	20

SERIES XI.

Magnetizing Current = 256 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
4.04	113	2.00	41
3.40	95	1.53	32
3.04	76	1.25	24
2.66	61	0.94	16
2.26	54	...	...

SERIES XII.

Magnetizing Current = 259 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
3.77	98	2.29	47
3.23	83	1.87	34
2.78	71	1.53	23
2.51	56	1.19	16

SERIES XIII.

Magnetizing Current = 275 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
3.33	54	2.35	29
2.93	46	2.05	23
2.63	37	...	...

SERIES XIV.

Magnetizing Current = 310 milliamperes.

Line Current.	Excursion.
3.12	38
2.87	28
2.30	12

These figures show that the change in the amplitude of the vibration of the diaphragm is approximately proportional to the change in strength of the line current, within the limits of line current and magnetizing current used and with the distance $\frac{1}{82}$ inch between the core and diaphragm. Some irregularities in the figures are due to a small variation in the strength of the magnetizing current, which was furnished by a dynamo machine whose speed fluctuated a little.

A series of observations was next made in which the magnetizing current was varied as with the previous Series I to VII, and the line current kept constant, but with the diaphragm at a distance of $\frac{1}{64}$ inch from the pole of the field-magnet. The results are given in Table IV, and those of all the series except XVII are shown graphically in Figure 4.

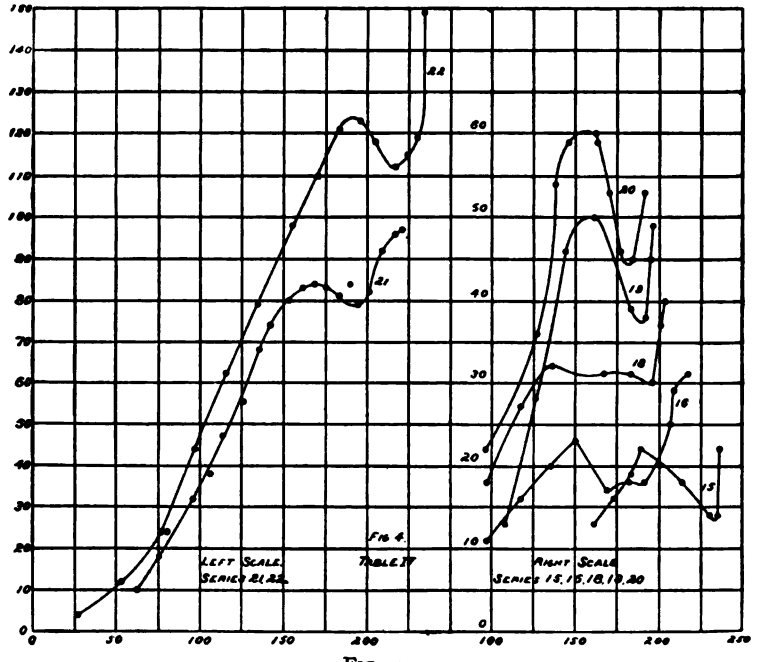


FIG. 4.

TABLE IV.

SERIES XV.

Line Current = 0.82 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
161	13	214	18
173	16	230	14
183	19	235	14
189	22	256	22

SERIES XVI.

Line Current = 1.25 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
97	11	182	18
117	16	191	18
135	20	207	25
150	23	209	29
169	17	217	31

SERIES XVII.

Line Current = 1.45 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
202	38	229	40
216	35	240	53

SERIES XVIII.

Line Current = 1.70 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
97	18	183	31
117	27	196	30
136	32	203	40
167	31	201	37

SERIES XIX.

Line Current = 2.05 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
108	13	183	39
126	28	192	38
144	46	195	45
161	50	196	49

SERIES XX.

Line Current = 2.18 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
96	22	163	59
127	36	170	53
138	54	177	46
146	59	184	45
162	60	191	53

SERIES XXI.

Line Current = 2.35 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
62	10	161	83
75	18	168	84
80	24	175	83
96	32	183	81
106	38	190	84
113	47	195	79
126	55	201	82
135	68	209	92
142	74	217	96
153	80	221	97

SERIES XXII.

Line Current = 3.55 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
27	4	183	121
53	12	196	123
76	24	205	118
97	44	217	112
115	62	224	115
134	79	230	119
155	98	234	149
170	110	...	...

It will be noticed from the data given in the tables and the curves that, with the core of the magnet at a distance of $\frac{1}{64}$ inch from the diaphragm, a first maximum of the excursion is reached with a magnetizing current not far removed from 160 milliamperes, while with a distance of $\frac{1}{32}$ inch the maximum excursion occurred when the magnetizing current had a value of about 225 milliamperes.

With the diaphragm thus close to the magnet it was observed, as will be seen from the figures, that after the amplitude of the vibration of the diaphragm had begun to decrease, owing to the approach of the diaphragm toward saturation, there was a later increase of this amplitude, which rose even to an amount greater than for any previous value of the magnetizing current. This was brought about by the motion of the diaphragm towards the pole, the diaphragm assuming a new position of equilibrium under the increased pull of the magnet. The effect of increased proximity of the diaphragm to the core more than makes up for the opposing effect of a closer approach of the diaphragm toward saturation.

A separate study of the variation in the excursion after the second rapid rise began was made by using the strongest possible magnetizing current below that which pulled the diaphragm into contact with the core, viz., 204 milliamperes, and varying the line current, the excursions being measured as before. The results are given in Table V, and shown graphically in Figure 5.

TABLE V.

SERIES XXII *a*.

Magnetizing Current = 204 milliamperes.

Line Current.	Excursion.	Line Current.	Excursion.
3.15	137	2.10	66
2.86	122	1.74	48
2.63	98	1.34	30
2.37	83	...	...

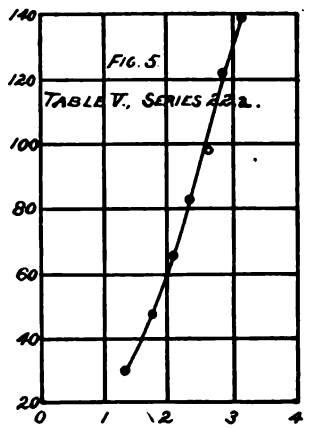


FIG. 5.

Table VI and Figure 6 show the result of a similar series of measurements with the diaphragm at a distance of $\frac{3}{256}$ inch from the core. Here the first maximum of the excursion is attained with a magnetizing current of about 100 milliamperes.

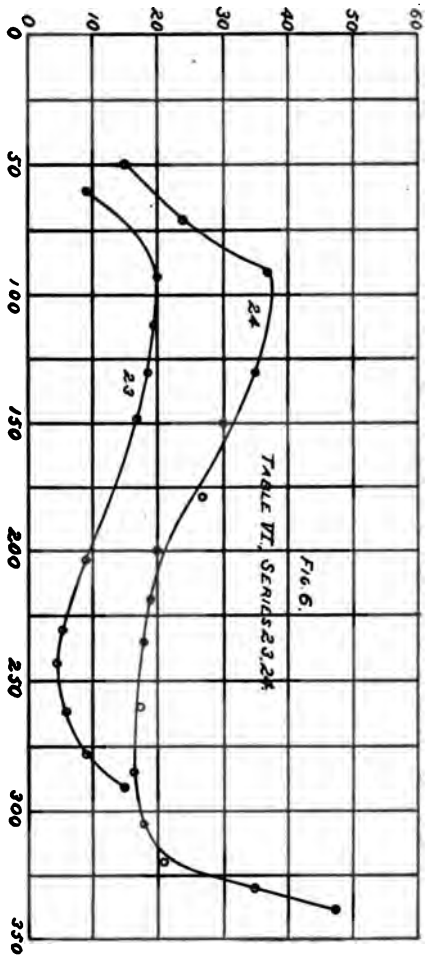


FIG. 6.

TABLE VI.

SERIES XXIII.

Line Current = 1.40 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
291	15	148	17
278	9	130	18.5
262	6	112	19.5
243	4.5	93	20
230	5.5	60	9
203	9	...	...

SERIES XXIV.

Line Current = 1.65 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
338	47.5	200	20
330	35	179	27
320	21	150	30
305	18	130	35
285	16.5	91	37
260	17.5	71	24
235	18	50	15
218	19	...	...

With the diaphragm at a distance of $\frac{1}{128}$ inch from the core, the values for the excursion given in Table VII were obtained. These are shown graphically in Figure 7. Here the final rise of the curve has begun even with the lowest magnetizing force employed.

TABLE VII.

SERIES XXV.

Line Current = 1.26 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
61	26	39	10
51	18	28	7

SERIES XXVI.

Line Current = 2.25 milliamperes.

Magnetizing Current.	Excursion.	Magnetizing Current.	Excursion.
61	69	39	22
51	48	28	12

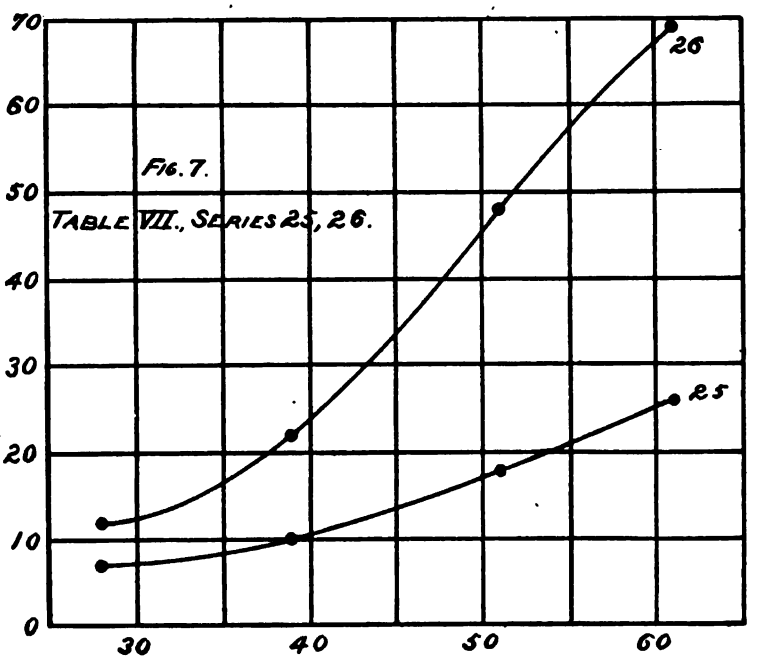


FIG. 7.

Table VIII shows the manner in which the mean position of the diaphragm varies when the magnetizing current is increased. There is no current flowing through the line coil. The distance of the diaphragm from the core with no magnetizing current flowing was $\frac{1}{128}$ inch.

TABLE VIII.

SERIES XXVII.

Magnetizing Current.	Deflection.	Magnetizing Current.	Deflection.
0	0	50	286
14	12	61	546
28	48	72	1020
39	145	...	...

ROGERS LABORATORY OF PHYSICS,
June, 1892.

NATIVITY AND OCCUPATION OF MEMBERS OF THE MASSACHUSETTS LEGISLATURE.[1]

By F. H. HOWLAND, S.B., and D. R. DEWEY, Ph.D.

Received October 16, 1893.

I. NATIVITY.

In view of the great change which is taking place in the character of the population of the country as to its immediate origin, an inquiry is undertaken in the following paper to determine how far citizens of foreign birth have engaged in public political life in the State of Massachusetts during the past half century. The material from which the statistics are gathered may be found in the State Library in Boston. The years 1847–1864 are covered by *Poole's Register;* data for 1866–1879 in the *Journal* of the House of Representatives; and for the remaining years there is abundant material in bound extracts from the Boston *Journal.* There is no record for the years previous to 1847 save in unpublished manuscripts, nor for the year 1865.

In the period under observation, 1847–1891, there has been but one House, that of 1848, which consisted entirely of native-born members. The number of foreign-born representatives during this period ranged from one to twenty-six, the maximum being reached in 1881, 1883, and 1884. In 1891, the last year of the term under consideration, there were 19 of foreign birth out of a total representation of 240.

The Senate of Massachusetts is composed of forty members. There have been eleven years since 1846 when there were no foreign-born citizens in this body; seventeen, when there were but two; and one year, 1891, when the maximum number, five, was reached.

The maximum percentage of foreign-born in the House is 10.8 in the years already referred to, 1881, 1883, and 1884; and in the

[1] Abstract of thesis submitted by F. H. Howland, May, 1893.

Senate 12.5 in 1891. As might be presumed, the larger part of foreign-born members of the General Court, as the Massachusetts Legislature is termed, were born in England, Ireland, Scotland, and British colonies. Ireland has furnished by far the largest number, 274, or 55 per cent. of the foreign-born in the House and 29 in the Senate. England comes next, with a total of 92 in the House and 12 in the Senate. Canada is credited with 58 in the House and 12 in the Senate; Scotland with 47 in the House and 6 in the Senate; and the British West Indies, Isle of Jersey, and Isle of Man, 6 in the House and one in the Senate.

Germany has sent fifteen; Holland, two; and France, Turkey, Switzerland, one each, to the House.

The changes which have taken place will be understood more clearly if the period 1846–1891 be broken up into decades. This is done in the following table:

HOUSE OF REPRESENTATIVES.

Years.	Total Number of Members in House varied.	Average Number returned Annually, Born in						
		Ireland.	England.	Canada.	Scotland.	Other English Possessions.	Other Foreign Countries.	Total.
1847–50	253–297	.0	.5	.1	.3	.1	.0	1.0
1851–60	240–401	.9	1.0	.5	.5	.1	.0	3.0
1861–70	240	3.8	1.4	.4	.8	.1	.2	6.7
1871–80	239–240	9.6	2.8	1.6	.6	.0	.6	15.2
1881–90	237–240	11.9	3.3	3.0	2.3	.3	1.0	21.8
1891	239	12.	2.0	2.0	2.	.0	2.	20.

Of course it must not be supposed that there were 274 different individuals born in foreign countries who during this period gained the distinction of a position in the General Court. The same person may have been returned, and probably was returned several times, and some of those who are recorded as members of the House of Representatives are found in the list of the Senate. But this does not affect the statistics for purposes of comparison, as the same fact is true of the native-born members.

The Senate statistics do not vary much from the above in the tendencies indicated. During the same periods, out of a total membership of forty, the foreign-born have been as follows:

SENATE.

Years.	Total Members.	Foreign-Born.
1847–50	40	.1
1851–60	40	..
1861–70	40	1.5
1871–80	40	1.2
1881–90	40	2.1
1891	40	5.

It will be observed that the great increase of foreign-born representatives took place in the decade 1871–1880; and since then that the ratio has been quite constant. A further investigation showed that by far the larger number of the foreign-born were returned for Boston districts, and had their residence in that city.

For a portion of the period over which the inquiry extended it was possible from the documents at hand to tabulate the political faith of the foreign-born members. In the years 1880–1891, of the 146 representatives of Irish birth only 9 are credited to the Republican party, while 135 stand in the Democratic column. One is entered as a Greenbacker, and another in the People's party.

Of the 40 entries of English birth, however, 24 are in the Republican and 16 in the Democratic column. But about one third of the members from Canada, Scotland, and other English possessions are enrolled as Republicans, the total being 18 Republicans and 39 Democrats. In the Senate there are 29 foreign-born entries in the years 1880–1891, and of these 21 belong to the Democratic side.

To sum up then: About one tenth of the members of the Legislature to-day are foreign-born; of this fractional body, Ireland furnishes a little more than half. Generally the Irish contingent will be found in the Democratic column, while the other foreign elements are more evenly divided. These statistics bear out common impressions in regard to the constitution of our legislative body, but it would be

interesting to have a similar inquiry made for a Western State, as, for example, Wisconsin, which has a large Teutonic and Scandinavian population.

2. OCCUPATION.

Records of the occupations of the members of the Legislature are less satisfactory than those of nativity. The principal titles under which members are entered are those of lawyers, farmers, manufacturers, and merchants. Other occupations, as clergymen, machinists, editors, physicians, etc., appear in the returns, but there is no uniformity of listing from year to year. It is thus impossible to make comparison which will include all the members; but in spite of this necessary defect it is possible to note certain general tendencies. Using the same periods of time as in the analysis of nativity, we find the following occupations entered for members of the Senate. The figures are averages derived from the several years in each period.

OCCUPATIONS OF MEMBERS IN SENATE.

	Lawyers.	Farmers.	Manufacturers.	Merchants.
1847–50	10.7	8.7	7.7	5.5
1850–60	8.4	5.6	4.5	6.7
1861–70	10.4	3.3	7.7	5.4
1870–80	10.2	2.5	8.1	5.6
1880–90	9.8	2.2	6.2	3.1

As the Senate generally has had 40 members throughout the period, it will be observed that while in the earlier decades the above categories would include two thirds of the membership, in the last decade not more than one half were thus accounted for. There were more who really belong in the mercantile class than appear above, the deficiency being due to a refinement of recording which did not formerly prevail. Lawyers have held their own, as well as the mercantile class, while the farmers have steadily declined in influence.

In the House we find the same tendencies. In the membership of this body until 1855 the farmers had from one fourth to one third of the members; but latterly only very rarely in a House of 240 members are there 30 farmers. Lawyers have increased slightly

in numbers, and the same is true of manufacturers and merchants. There was formerly a substantial group of clergymen, but now they appear only occasionally. In the period 1847–50, there was, for example, an average of 9.5 clergymen; 1851–60, 7.8; 1861–70, 8.5; 1871–80, 3.5; 1881–90, 1.9.

The following table shows the average number of farmers and lawyers, it not being possible to classify accurately other occupations.

HOUSE OF REPRESENTATIVES.

	Total Members in House.	Farmers.	Lawyers.
1847–50	253–297	72	28.5
1851–60	240	82.6	26.7
1861–70	240	37.7	24.5
1871–80	239–240	26.8	27
1881–90	237–240	20.8	34.2

METALLURGICAL LEAD EXHIBITS AT THE COLUMBIAN EXPOSITION.[1]

By H. O. HOFMAN.

Received October 24, 1893.

THE mining engineer who visits the Columbian Exposition is gratified to find a department of mines independent and unattached to any other and housed in a commodious building of ample proportions (700 by 300 feet) and artistic appearance. On entering, his first impression is of the richness and tasteful arrangement of the exhibits, and a closer inspection shows the great variety of minerals and ores which have been gathered from all parts of the world and afford a rare opportunity for study. In turning, however, to the metallurgical division, he is disappointed, and especially so in the part devoted to lead. It seems really a pity that the country which, next to Spain, is the greatest producer of lead in the world, and has the finest smelting and refining works, should represent this great industry in so inadequate a way. The leading works have done practically nothing at all, and the slight showing that is made comes entirely through the different States and Territories where the works are located. In this way the exhibits have been collected and placed with so little system that their educational value is almost, if not entirely, lost, although the management has tried to supply this deficiency by the aid of diagrams and drawings. These are, however, necessarily of so general a character that the connection between them and the exhibits has largely to be guessed at. In marked contrast are the methods of the foreign exhibitors, who have clearly explained by charts, pamphlets, etc., whatever they have sent.

It was intended that the whole metallurgical department should be located in the wide gallery (60 feet) running around all four sides of the building, but owing to the fact referred to above, that the metallurgical lead exhibits were almost exclusively made by the several

[1] Reprinted from the Engineering and Mining Journal, October 14, 21, 28, 1893.

States and Territories as such, they are to be found, with few exceptions, on the ground floor.

It will be the aim of the following paper to review them under three general heads:

1. Apparatus. 2. American and Foreign Exhibits. 3. Processes.

APPARATUS.

The apparatus exhibited represents principally the smelting industry; to a very slight extent that of refining. A model of a circular water-jacket furnace for smelting copper ores, built in 1862 by Messrs. B. Williams & Co., is of interest as a bit of history. It resembles so much the 48-inch furnace in common use to-day for the same purpose that it might be taken for a model of it.

The Chicago Iron Works, of Chicago, Illinois (southeast end of the ground floor), have two specimens of sampling apparatus; a sample-grinder which is of the usual coffee-mill type, but has a few improvements to facilitate the removal of the hopper and the cleaning and exchanging of the shoe and die; and the Brunton quartering shovel,[1] which much simplifies the cutting down of the sample when this is done by hand, and also gives as accurate results as can be obtained in any other way. A full-sized blast-furnace, 33 by 84 inches, is an imposing feature of the exhibit. It has four water-jackets made of low-carbon steel, and five tuyere holes, $3\frac{1}{2}$ inches in diameter, on either side, showing a slight downward pitch. The cooling-water of the jackets, introduced through the usual water-feeders, is discharged through wrought-iron pipes into thin cast-iron annular troughs ($5\frac{3}{4}$ inches wide, $\frac{1}{4}$ inch thick) fastened to the four columns supporting the shaft, and passes off underground through 3-inch standpipes. The crucible is enclosed at the sides by $\frac{3}{8}$-inch boiler iron, at the ends by the usual cast-iron plates, the whole being firmly tied by heavy rails. A novel feature is the manner of delivering the blast to the furnace. At the bustle pipe the usual canvas bag is replaced by an inclined sheet-iron pipe. This has fastened to its lower end a cast-iron casing having the wind-gate. From the casing a cast-iron elbow with ball joint is suspended by two spring bolts revolving around trunnions placed diagonally that the elbow may be swung sideways; the bolts press the ball of the elbow against the socket of the casing and keep

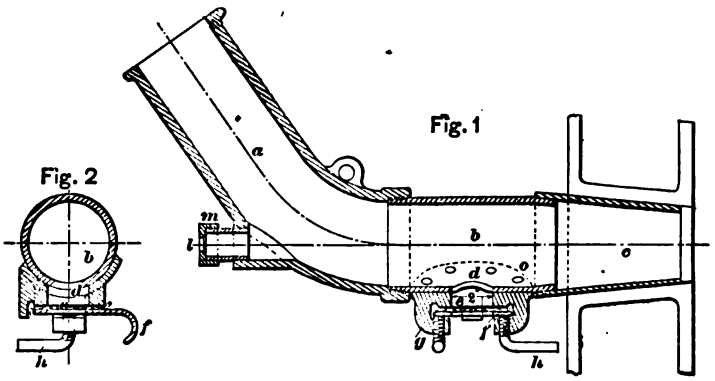
[1] For description and illustrations see Engineering and Mining Journal, June 20, 1891.

the joint air-tight. A cast-iron tuyere box, with fusible plug for discharge of melted slag, is fastened by means of four set screws to the jacket; on either side it has a tightening hook which presses the elbow, when swung back into position, against a rubber packing, making this joint also air-tight. Of the accessory apparatus there is an ordinary slag pot with the usual paraboloid bowl, 22 inches in diameter and 18 inches deep; the wheels are 22 inches in diameter and have straight spokes and friction bearings. There is also an overflow pot to assist in the separation of matte from slag; the bowl is 30 inches in diameter, and 18 inches deep; the wheels are 28½ inches in diameter, have staggered spokes, and also friction bearings. A positive pressure blower, marked No. 4, made by the Connersville Blower Company, Connersville, Indiana, which resembles the well-known Root blower, closes the list.

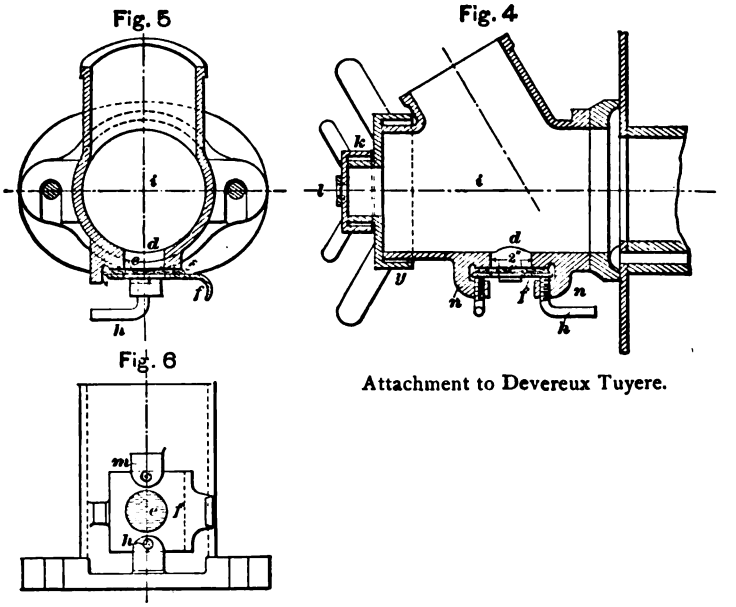
In the southeast part of the ground floor the well-known firm of Messrs. Fraser & Chalmers, Chicago, Illinois, has its extended exhibit, of which the lead-smelting apparatus forms but a small part. The sampling of ores is represented by two crushers — a Blake 15 by 9 inches, and a Dodge 8 by 12 inches — intended to crush the ore from the mine for the Bridgman mechanical ore-sampler.[1] This machine, which came on the market only a couple of years ago, belongs to that class of sampling apparatus which takes the sample at short intervals from the whole width of a running stream of ore. Two types, called A and B, are exhibited. The former, of wrought iron, occupying a floor space 3 by 4 feet, and 7 feet 6 inches in height, gives two samples, the original and duplicate, thus furnishing an important means of controlling the operation. It has a capacity of from 15 to 25 tons of ore per hour, and is easily cleaned. Type B is a small machine of cast iron; it occupiès a floor space only 18 inches square, and is 36 inches high. It gives a single sample, and is used for cutting down either the main sample from machine A after it has been recrushed by rolls (the exhibit shows a pair of geared rolls 10 by 16 inches) or small amounts of finely crushed ore. Its capacity varies from two to four tons per hour. These machines have found much favor, and with reason, where they have been introduced. A sample-grinder of the well-known coffee-mill pattern concludes the list of sampling apparatus. The smelting is represented by an imposing full-sized

[1] For illustrations see Transactions American Institute Mining Engineers, 20, 416.

blast-furnace, 42 by 120 inches, a size much in use to-day. The jackets are cast iron and of six different patterns: front two, back two, side one, and tapping-jacket one. A late improvement is to connect the jackets, either in pairs or all together, by means of short pieces of 1-inch pipe inserted below the water-feeders and joined by rubber hose, the advantage of the device being that if the jackets are all connected no single one can ever run dry, and if in pairs, the danger is greatly lessened, as when the water inflow of one jacket, for some reason or other, is insufficient, it will be supplemented by its neighbor. The crucible of the furnace is enclosed in the usual cast-iron plates, strengthened by ribs. The slag spout shows an improvement in being water-cooled — an interesting feature if we consider the amount and character of charge furnaces have to put through to-day. A beautiful device, which must strike every smelting man with pleasure as soon as he looks a little closely at the furnace, is the Davies Slag Escape, as it is so simple, convenient, and useful. It consists of an opening in the underside of a tuyere pipe or tuyere box closed by a linen or paper diaphragm. As soon as any slag, entering the pipe or box, touches the diaphragm, it burns a hole in it, and the noise of the escaping blast calls the attention of the keeper to the accident as soon as it has occurred. The illustrations — Figures 1 to 3 and 4 to 6, taken from working drawings furnished by Messrs. Fraser & Chalmers — give the necessary details. Figures 1 to 3 show the escape attached to the common tuyere pipe; the cast-iron elbow *a*, with peephole *l*, closed by cap *m*, is screwed to a piece of 4-inch wrought-iron pipe *b*, which has the opening *d* for the escape of the slag and is riveted to the conical brass nozzle *c* entering the furnace. To the underside of *b* is riveted the flange *o*, with its lugs *g*. These receive in a suitable recess the perforated piece of sheet iron *f*, having on its upper surface a bit of linen or paper *e*, and the screws *h* press it against the seat, thus making an air-tight joint. If slag entering the tuyere pipe burns a hole in the diaphragm this can be replaced in a moment by loosening the screws *h* and drawing out the sheet iron. Figures 4 to 6 represent the slag escape attached to the Devereux tuyere box *i*, which is closed at the back by the cover *y*, the collar of which has a cap *k*, with the peephole *l* in the center. The cylindrical tube with diagonal bore, another characteristic of the Devereux tuyere box, is not shown. The slag escape differs from that of Figures 1 to 3 in having the lugs *n* cast on the wind-box and not riveted to it, thus greatly sim-



Attachment to Ordinary Tuyere.



Attachment to Devereux Tuyere.

THE DAVIES SLAG ESCAPE.

plifying and cheapening the arrangement. The accessory apparatus are represented by two Root positive blowers, Nos. 6 and 7, which have respectively a displacement of 42 and 65 cubic feet of air per revolution; the former machine is driven by a horizontal engine, the latter by a vertical engine resting on the same bed plate. A typical slag pot, 24 inches in diameter, 16½ inches deep, with wheels 24 inches in diameter, having straight spokes and steel roller bearings and several molds holding about 100 pounds of lead, concludes the list.

The apparatus used in refining are represented by samples of graphite retorts and crucibles, basic bricks, and a drawing of the Roesing lead pump.

The accompanying drawing, Figure 7, shows the largest retort made by the Joseph Dixon Crucible Company, of Jersey City, New Jersey; the next smaller size exhibited is 35 inches high, 7½ inches wide at the neck, 19¾ at the belly, and 13½ at the bottom.

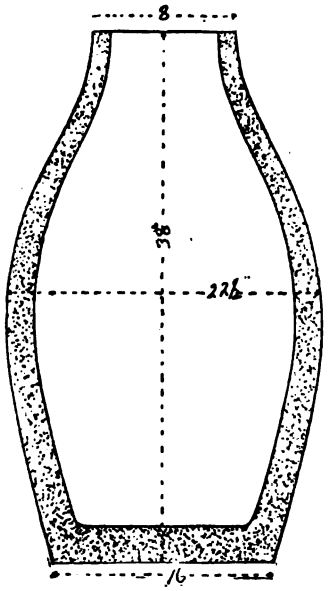


FIG. 7. THE DIXON GRAPHITE RETORT.

The retorts of the Phœnix Manufacturing Company, of Taunton, Massachusetts, are a little higher and narrower, the dimensions varying from 30 to 40 inches in height, and from 15 to 17 inches in width. The retorts of Robert J. Taylor & Son, of Philadelphia, are 36 inches high, 7½ inches wide in the neck (which is 6 inches long), 19 at the belly, and 13 at the bottom. The last exhibit of retorts is that from the Walker Mining Company, of Ottawa, Ontario, and Graphite City, Quebec. They are 36 inches high, 8 inches wide at the neck, and 18 inches at the belly. A great advance has been made in the manufacture of retorts. This is easily seen if we consider that their capacity has been raised from 200 to over 1,000 pounds of zinc crust, and their life from 14 charges to an average of 36, running even as high as 40 charges.

An interesting exhibit is that of the Spaeter Basic Bricks, of

Veitsch, Styria. They have, according to an analysis by Wedding,[1] the following composition:

SiO_2, 3.40	CaO, 1.76
Al_2O_3, 0.82	MgO, 85.30
Fe_2O_3, 7.79	99.07

The bricks are not only well burnt but slightly sintered, so that they can stand exposure to the air any length of time without slacking or deteriorating as would ordinary dolomite bricks. They have been used to line a cupelling furnace, and gave great satisfaction as far as durability was concerned; but their price was too high. The Pittsburg Testing Laboratory, Limited, Pittsburg, Pennsylvania, the agent for this country, quotes, July 13, 1893: Magnesite brick, normal size, $47.50 per ton, c. i. f., New York; calcined magnesite, $22 per ton; crude magnesite, $14.74, a price which may induce home manufacturers to replace the imported article with a native product, in view of the market it would find with the manufacturers of basic steel in addition to its use in the concentrating of copper matte and the refining of metallic copper.

The Roesing steam-pump of the German exhibit is a very simple, ingenious device for removing the molten lead from kettles to molds or other receivers which stand on the same level. It is described in the *Engineering and Mining Journal*, November 28, 1885, and its present improved form illustrated in the *Berg und Hüttenmännische Zeitung*, 1889, page 262. It has found much favor in the older European works, most of which are built on a horizontal plane. The refining works in this country being all built on an inclined plane, the kettles are better emptied by means of the Steitz siphon. In any case where a siphon cannot be applied, the steam-pump remains the best alternative.

AMERICAN AND FOREIGN EXHIBITS.

The description of the American exhibit will necessarily be short, owing to the meagerness of the material. Of Mississippi-Valley

[1] See Hofman, Engineering and Mining Journal, May 27, 1893, and Minutes of Proceedings of the Institution of Civil Engineers of Great Britain, 112, 381.

producers, Wisconsin shows about 60 bars of soft lead, Kansas is satisfied with a hexagonal column of about 120 bars from Galena; Missouri has a few small specimen bars from the St. Joseph Lead Company and a series of samples of the products obtained in working the Lewis-Bartlett process by the Picher Lead Company, from Joplin, to which reference will be made under the third head of processes.

Of the argentiferous lead producers only two are represented — Utah, by a few bars of base bullion and refined lead from the Mingo and Germania works; and Colorado, by a set of metallurgical specimens collected by the State School of Mines from the principal smelting works of Denver, Pueblo, and Leadville. Denver is represented by the Omaha & Grant Smelting and Refining Company, and the Globe Smelting and Refining Company; Pueblo, by the Pueblo Smelting and Refining Company, the Colorado Smelting Company, and the Philadelphia Smelting and Refining Company; and Leadville, by the Harrison Reduction Works and the American Smelting Company; the products of the American Zinc-Lead Company, of Canyon City, will be discussed under processes. The specimens are quite numerous, and might be very interesting if a key to them were given to the visitor, but this is missing; the collection is labeled just as an individual might label his private collection for his own use, but an exhibit for the World's Fair ought to have been treated differently.

The foreign exhibitors have done infinitely better. They have as a rule made the information which a visitor would be likely to require easily accessible.

The German exhibit represents the lead industry of the Upper and Lower Hartz Mountains and of Upper Silesia. It consists of specimens, charts explaining the processes, drawings and models of apparatus and a series of pamphlets. The specimens in the cases are numbered to correspond with the products indicated in the charts.[1] From the Upper Hartz the five silver-lead smelting and refining works are represented. The ores treated are galena concentrates running from 55 to 60 per cent. lead, and from 23 to 30 ounces silver to the ton. An average sample

[1] The analyses relating to the Hartz Mountains are taken in part from the literature on the subject, in part from private notes collected on the spot in 1890.

of all the ore smelted at Clausthal in 1889 showed the following composition:

Galenite,	74.04 (Pb 64.13, S 9.91)
Argentite,	0.10 (Ag 0.085, S 0.015)
Stibnite,	0.80 (Sb 0.58, S 0.22)
Chalcopyrite,	1.15 (Cu 0.40, Fe 0.35, S 0.40)
Sphalerite,	7.46 (Zn 5.00, S 2.46)
Pyrite,	0.60 (Fe 0.28, S 0.32)
Siderite,	2.27 (FeO 2.41, CO_2 0.86)
Rhodochrosite,	0.48 (MnO 0.30, CO_2 0.18)
Magnesite,	0.35 (MgO 0.17, CO_2 0.18)
Calcite,	1.71 (CaO 0.96, CO_2 0.75)
Gypsum,	1.92 (CaO 0.62, SO_3 0.90, H_2O 0.40)
Barite,	0.00
Alumina,	1.32
Silica,	8.57
	100.77

The ores are smelted raw in circular and oblong blast furnaces 16½ feet high from center of tuyeres to charging door, and 3⅛ feet wide at the tuyere level, with a pressure of 1 inch quicksilver. Water-jackets are not used as yet. The base bullion, with about 40 ounces silver to the ton, has the following composition:

	Clausthal.	Lautenthal.	Altenau.	Andreasberg.
Bi	0.0048	0.0082	0.0039	0.01955
Cu	0.1862	0.2838	0.2399	0.34730
Sb	0.7203	0.5743	0.7685	0.38858
Sn	.....	.....	.....	0.17149
As	0.0664	0.0074	0.0009	0.06520
Ag	0.1412	0.1431	0.1400	0.09300
Cd	trace.	trace.	trace.	trace.
Fe	0.0664	0.0089	0.0035	0.00544
Ni	0.0023	0.0068	0.0028	0.00630
Co	0.00016	0.00035	0.0002	.....
Zn	0.0028	0.0024	0.0025	0.00161
Pb, by difference	98.80944	98.96475	98.8378	98.90153
	100.00000	100.00000	100.0000	100.00000

It is desilverized by the Parkes process without being softened. The liquated zinc-crusts from several charges, assaying from 500 to 700 ounces silver per ton, are heated in a cast-iron desilverizing kettle to a bright red, and decomposed by introducing through a curved cast-iron pipe superheated steam. A rich lead results, assaying from 700 to 1,060 ounces silver per ton, with so-called rich oxides, a mixture of zinc oxide, lead oxide, and shots of rich lead assaying from 360 to 540 ounces silver per ton. The rich lead is cupelled and any resulting doré silver parted with sulphuric acid. The oxides are treated with dilute, warm sulphuric acid, the zinc sulphate formed is concentrated in lead-lined pans, purified, and crystallized and sold to manufacturers of lithopon — a white paint which is an intimate mixture of barium sulphate and zinc sulphide, formed by the action of solutions of barium sulphide and zinc sulphate upon each other. The paint has a good color and body; the details of the process, however, are kept secret.

The zinc remaining in the desilverized lead is oxidized by steaming, and the resulting powdery substance, after it has been washed to remove shots of lead, etc., and dried, is sold as a yellow paint. The refined lead, with 99.98 per cent. lead, goes straight to the market; some second-class lead with 99.94 per cent. lead is also made. The antimony contained in the base bullion is worked for hard lead with about 16 per cent. of antimony. The following analyses give the composition of the various products of the refinery.

	Zinc-crust.		Rich lead.		Rich oxide.		Flue dust.	Corroding lead.		Second-class lead.	Hard lead.			Washed poor oxides, Paint.
	Altenau.	Lauten-thal.	Altenau.	Lautenthal.	Altenau.	Lauten-thal.	Altenau-Lauten-thal.	Altenau.	Lautenthal.	Lautenthal.	Altenau.	Lauten-thal.	Andreas-berg.	Lauten-thal.
Pb . . .	77.675	77.820	96.3448	95.1404	37.84	30.06	0.71	99.96634	99.98480	99.94000	78.83	82.65	76 39	.....
PbO . .	4.75	4.00	.....	.....	32.14	36.87	2.28	.....	.....	.....	.....	.....	.....	33.40
Bi . . .	.....	.....	0.0142	0.0169	.....	.....	.....	0.02213	0 00329	0.00323	0.06	.....	.....	.....
Bi_2O_3 . .	1.72	0.37	.....	.....	0.43	0.44	.....	.....	.....	.....	.....	.....	.....	.....
Cu . . .	1.12	0.82	0.8279	0.4645	1.12	1.24	0.17	0.00012	0.00080	0.04178	0.55	0.61	0.70	.....
Ag . . .	1.855	2.420	2.4100	3.6500	1.245	1.855	0.03	0.00050	0.00035	0.00200	.....	.....	.....	.....
As . . .	trace.	trace.	.....	.....	.....	.....	trace.	.....	.....	.....	0.60	.....	1.33	.....
As_2O_3 . .	.....	.....	.....	.....	trace.	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sb . . .	.....	.....	0.3914	0.7201	.....	.....	0.17	0.00739	0.00796	0.01079	19.94	16.75	21.83	.....
Sb_2O_3 . .	0.63	0.98	.....	.....	1.06	0.57	.....	.....	.....	.....	.....	.....	.....	.....
Fe . . .	.....	.....	0.0054	0.0044	.....	.....	.....	0.00177	0.00100	0.00073	0.02	trace.	0.02	.....
Fe_2O_3 . .	1.87	1.04	.....	.....	1.44	3.82	0.34	.....	.....	.....	.....	.....	.....	.....
Zn . . .	11.78	12.11	0.0027	0.0023	1.35	1.90	0.12	0.00094	0.00092	0.00030	trace.	trace.	trace.	.....
ZnO . .	0.60	0.44	.....	.....	23.37	23.24	95.60	.....	.....	.....	.....	.....	.....	67.60
Cd . . .	trace.	trace.	trace.	trace.	trace.	trace.	.....	0.00046	0.00088	.....	.....	.....	.....	.....
Mn . . .	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ni . . .	trace.	trace.	0.0036	0.0040	trace.	trace.	.....	0.00035	.....	0.00117	0.02	trace.	trace.	.....
Co . . .	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Al_2O_3 . .	.....	.....	.....	.....	.....	.....	0.24	.....	.....	.....	.....	.....	.....	.....
Insol. . .	.....	.....	.....	.....	.....	.....	0.42	.....	.....	.....	.....	.....	.....	.....

The matte, with about 10 per cent. of lead, 4 per cent. of copper, and 10 ounces of silver to the ton, has the following composition:

Pb	12.44	SiO_2	1.22
Cu	3.49	CaO	0.51
Sb	0.13	MgO	0.05
Ag	0.035	K_2O	0.13
Fe	48.64	Na_2O	0.10
Zn	4.31	S	25.65
Mn	trace	O	2.03
NiCo	0.11		98.845

It is repeatedly roasted in heaps and smelted in low shaft furnaces until it is concentrated into black copper. This is refined in a reverberatory furnace and then desilverized either by vitriolization or by electrolysis according to the prevailing market price of blue vitriol. The residual mud containing lead and silver is worked up in cupelling the rich lead or goes back to the blast furnace.

The slag, with less than 1 ounce of silver to the ton and 1 per cent. of lead, goes to the dump. The following analysis shows its character:

SiO_2	31.09	ZnO	8.01
$BaSO_4$	0.51	MnO	0.86
Pb	1.70	NiCo	0.03
Cu	0.21	BaO	1.04
Sb	0.22	CaO	4.39
Ag	0.002	MgO	0.05
FeO	40.64	K_2O	0.58
Al_2O_3	6.98	Na_2O	0.35
P_2O_5	0.79	S	3.55
			101.002

The ores of the Lower Hartz are principally sulphide copper ores; they contain, however, some sulphide lead ores rich in zinc, as seen by the following average rational analysis:

Blende	36	Galenite	14
Pyrite	24	Chalcopyrite	1.5
Barite	16	Gangue	8.5
			100.0

They are roasted in heaps and then leached with water in revolving wooden barrels to extract the zinc sulphate formed, which is treated as above. It has the following composition:

ZnO	25.45	SO_3	29.54
MnO	2.32	H_2O	41.67
FeO	0.47	CuO	trace
			99.45

The leached ore containing

PbO	9	$BaSO_4$	20
ZnO	25	Cu	0.75
Fe_2O_3	25	Ag	0.015
S	5		

is smelted in blast furnaces for base bullion and matte to be treated as above and slag of a very peculiar character:

SiO_2	16.90	Al_2O_3	6.31
FeO	35.05	CaO	6.05
ZnO	19.64	Pb	0.50–0.75
$BaSO_4$	10.24 (=8.13 BaS)		

Upper Silesia is represented by the smelting and refining works of Tarnowitz. The ores are a mixture of lead sulphide and carbonate, and have a calcareous gangue. They are rich in lead and zinc and very poor in silver, and are worked in the well-known Tarnowitz reverberatory furnace for base bullion and rich residue. This is then smelted in a blast furnace with ore not suited for the reverberatory furnace. The resulting base bullion and matte are treated in a way similar to that used in the Upper Hartz. Special provisions are made at these works to draw off all the lead fumes. This was necessary because, with increased production, their bad effect on the health of the operatives became conspicuous.

England has only one case 4 by 8 feet, which contains the products of the Dee Bank Lead Works, Walkers, Parker & Co. Ores are there smelted both in the Flintshire furnace and the blast furnace. The Pattinson as well as the Parkes process is in use for desilverizing base bullion. Both are represented by their intermediary and end products; the applications of lead are found in samples of sheet lead, lead pipe, and shot; the lead compounds made by the firm are seen in the exhibits of litharge, red lead, orange lead, and dry white lead; the process of manufacture of the last by a pate of lead before and after corroding.

France shows only a few bars of lead from Laurion produced by the "Compagnie Française des Mines du Laurium," which are better discussed under the Greek exhibit, where they are duplicated.

Spain has only a few bars of lead and some bags of shot.

Greece has a very interesting metallurgical exhibit of 22 samples representing the industry of Laurion on the east coast of Attika. A pamphlet by Mr. A. Cordella, the General Manager of the Greek Metallurgical Company, gives the subjoined table of analyses:

No.	Metallurgical Products.	Pb. per ct.	Ag. ozs. per ton.	Fe. per ct.	SiO_2. per ct.	Zn. per ct.	CaO. per ct.	Al_2O_3. per ct.	As. per ct.	Sb. per ct.	Cu. per ct.	Mn. per ct.	Ash. per ct.	Fixed Carbon per ct.
1	Ancient land slags from Barbaliaki	10.70	17.78	11.90	33.80	5.40	13.80	3.90	.....	.....	.....	.....	.....	.....
2	Sea slags from Brysakia	11.50	13 12	12.30	26.50	5.60	14.70	3.60	.....	.....	.....	.....	.....	.....
3	Sea slags conglomerated	8.50	13.99	10.30	27.00	4.80	14.50	3.40	.....	.....	.....	.....	.....	.....
4	Sea slags with lead and litharge.	13.50	11.37	10.50	32.00	5.00	13.00	3.80	.....	.....	.....	.....	.....	.....
5	Slags with laurionite	10.00	11.23	10.50	30.00	5.00	15.00	3.80	.....	.....	.....	.....	.....	.....
6	Litharge	65.00	3.59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	Old slimes	10.30	53.90	10.55	42.50	5.95	6.30	4.50	.....	.....	.....	.....	.....	.....
8	Yellow eclovades	7.30	43.19	15.75	36.50	3.20	5.30	1.70	.....	.....	.....	.....	.....	.....
9	Eclovades Souriza	3 60	98 17	3.50	15.00	6.50	25.00	.....	.....	.....	.....	.....	.....	.....
10	Coarse sand (Products of modern concentration works)	31.65	126.70	5.55	21.50	7.20	18.10	.....	.....	.....	.....	.....	.....	.....
11	Fine sand (Products of modern concentration works)	32.65	82.63	7.05	11.00	7.20	17.30	.....	.....	.....	.....	.....	.....	.....
12	Fine slime (Products of modern concentration works)	5.25	52.41	9.64	42.20	4.30	8.00	6.70	.....	.....	.....	.....	.....	.....
13	Prepared bricks	10.20	72.91	10.35	20.00	4.30	15.50	3.00	.....	.....	.....	.....	.....	.....
14	Unroasted arsenical fumes	38.50	3.83	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	Roasted fumes	50.00	3.00	.....	.....	.....	.....	.....	35.00	3.50	.....	.....	.....	.....
16	Iron ore for shipping	.....	.....	37.97	3.80	1.20	5.80	.....	7.00	.....	.....	15.25	.....	.....
17	Iron ore for smelting	6.50	65.18	29.50	6.00	1.40	5.30	.....	.....	.....	.....	12.25	.....	.....
18	Base bullion	.....	73.50	0.014	.....	.....	.....	.....	0.374	0.713	0.31	.....	.....	.....
19	Speise	4.00	91.43	56.00	.....	.....	.....	.....	24.00	.....	5.00	.....	.....	.....
20	Refined lead	.....	0.58	0.049	.....	.....	.....	.....	0.0236	0.250?	0.0079	.....	.....	.....
21	Smithsonite	.....	.....	.....	.....	42.00	.....	.....	.....	.....	.....	.....	.....	.....
22	Lignite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.00	49.50

The exhibit is of historical as well as practical interest in that the dumps of the waste products show the character of the work done by the ancient Greeks and form to a large extent the raw material for the modern works, of which the other ores and the market, intermediary, and waste products are also shown. Mining began at Laurion at a very early date in the world's history, and flourished especially under Perikles and Themistokles in the fifth century B.C., when as many as 20,000 slaves were kept at work. The production then gradually decreased and came to a stop about the first century A.D., when the old dumps had been worked over again and the mines were considered to have been exhausted. In the sixties a French company was formed to work up the dumps from the ancient mines and concentration and smelting works, and also to open up again the mines from which the ancients had not only not extracted all the sulphide and carbonate lead ores, but had left untouched the zinc and manganiferous iron ores which form to-day such an important part of the products of the four companies of the region. They give employment to 7,000 men, and produced, from 1864 to 1892, 250,000 tons of base bullion averaging 57 ounces silver to the ton, 550,000 tons of manganiferous iron ore, and 500,000 tons of zinc ore (roasted smithsonite).

The ancient land slags (No. 1) come from the slag dumps of the old Greeks and go straight into the modern blast furnaces; the sea slags (No. 2), worked in the same way, are recovered by means of steam dredges from the sea; often they form a loose conglomerate with limestone (No. 3) and contain lead and litharge (No. 4); in some cases a new mineral, Laurionite $PbCl_2$, $Pb(OH)_2$ (No. 5), has been formed by the action of the sea water on the lead slags containing metallic lead and lead sulphide. Litharge is represented by No. 6. The old slimes (No. 7), which are so rich in silver, show that the ancients were not aware of the great losses of silver that are liable to take place in washing carbonate ores. Yellow eclovades (No. 8), from dumps of ancient mines, and eclovades Souriza (No. 9), from dumps of ancient dressing works, are both passed through modern concentration works, of which Nos. 10 to 12 are the samples. Bricks, No. 13, represent the bricked slimes ready to be charged into the furnaces. The arsenical fumes are collected in a flue of 4,000 feet length and 96 square feet section; their annual amount is from 3,300 to 3,900 short tons. They are purified by roasting in a small reverberatory furnace, whence result a residue (roasted lead fume No. 15) that goes

to the blast furnace and a refined white arsenic ready for the market. Nos. 16 and 17 are some of the ores mined by the companies to-day. The smelting is carried on in fourteen circular blast furnaces; the base bullion (No. 18) is for the most part sold to English, French, and German refining works, a small amount being desilverized at the works by the Parkes process to furnish sufficient soft lead (No. 20) for the home market. The speise (No. 19) formed is sold to a small extent, the bulk being worked up at intervals. Smithsonite (No. 21) is roasted before being shipped to reduce its weight. The last sample of the table is a lignite (No. 22), which is used in the roasting furnaces and under the boilers.

Japan has an interesting collection of models of furnaces used for smelting, liquating, and cupelling.

PROCESSES.

Under this head four exhibits will be discussed, each representing an invention of more or less importance, the first being the Lewis & Bartlett Bag Process of collecting lead fumes. The Picher Lead Company shows the products obtained by this process in their Lone Elm Works at Joplin, Missouri — pig lead, gray slag, lead fume, sublimed white lead A, and sublimed lead sulphate AA. Only an outline of the process need be given here as it has been described in full, with abundant illustrations, by Mr. E. O. Dewey in the *Transactions of the American Institute of Mining Engineers*, vol. XVIII, page 674.[1] It consists in working, in a water-jacketed ore-hearth with heated blast, pure galena ore for lead, gray slag, and fume; the fumes are drawn off from the furnace, by means of a fan, through a cooling pipe, and then made to pass through a series of suspended woolen bags. The filtered fumes are smelted with the gray slag from the ore-hearth in a slag-eye furnace, having also a heated blast, for lead, waste slag, and refined fume, which is recovered in a similar way as the impure ore-hearth fume and sold in the two grades already mentioned. It should be noted that, as the use of heated blast favors the volatilization of lead, the aim is rather to produce lead fume than metallic lead, as is the practice in other smelting works. This method of recovering lead fumes was introduced a few years ago at the works of the Globe Smelting and Refin-

[1] See also Hofman, Metallurgy of Lead, page 124.

ing Company, of Denver, Colorado, to recover the flue dust from the blast furnaces, and has since been perfected there.

The F. L. Bartlett Process[1] for the treatment of complex zinc ores is used by the American Zinc-Lead Company, of Canyon City, Colorado, which exhibits samples of ore treated and of the products obtained at their works. These are: argentiferous copper matte, slag, flue dust, dark-colored raw fume, and refined white pigment. The process consists in treating the ore — ZnS 45 per cent., PbS 9 per cent., CuFeS 4 per cent., FeS_2 42 per cent., and siliceous gangue, silver 10–20 ounces, and gold 0.1 ounce per ton — crushed to pea and dust size and mixed with 75 per cent. of fine coal, on a perforated iron grate for four hours with forced draught, with the result of driving off as fume a large proportion of the zinc, lead, and sulphur, to be collected in woolen filter bags, and a scoriaceous residue to be smelted for matte and slag. The dark-colored fumes, which are an intimate mixture of more or less oxidized zinc sulphide and lead sulphide, and finely divided carbon with some of the rarer volatile metals, if these are present, are made white by roasting, which completes the oxidation, and then ground to an impalpable powder. The resulting white paint, consisting of 58 per cent. zinc oxide and 42 per cent. lead sulphate, and assaying from 4 to 5 ounces silver to the ton, is said to have a good body. The residue from the "blowing-up mixture," the first part of the process, contains ZnS 12–15 per cent., Pb 1 per cent., Cu 1–2 per cent., Ag 10–20 ounces per ton, the balance being made up of slagged and matted iron. It is mixed with 5 per cent. lime and some copper ore, as this assists the separation of matte and slag in the presence of zinc and the collection of precious metal in the matte. The residue-charge is smelted in a low blast furnace run with hot blast and a hot top, both of which assist the volatilization of zinc and lead. The percentage of coke required is smaller than that in matting, as the sulphur in the charge furnishes part of the fuel that would otherwise be necessary. The slag aimed at is siliceous, to assist the volatilization. It runs from 35 to 42 per cent. silica, 2 to 7 per cent. zinc, the balance being made up by iron, and contains 0.75 ounces silver per ton, and is free from lead and gold. The matte runs from 75 to 200 ounces silver, and from 0.2 to 1.5 ounces gold per ton, from 30

[1] The notes taken at the exhibit have been supplemented from an article by the inventor in the Colorado State School of Mines Scientific Quarterly, vol. 2, no. 1, page 1.

to 40 per cent. copper, and from 2 to 4 per cent. zinc. In looking at the process one cannot help being struck by its similarity to the manufacture of zinc white and spiegeleisen from franklinite in New Jersey and Pennsylvania. It would be interesting to have a more complete statement of the work done at Canyon City than is obtainable at present, especially in the way of exact information about the proportion of silver and gold in the matte to that originally present in the ore.

The Hirsch Process. — All that is exhibited is a large-neck 8-ounce bottle half filled with a white substance and a supernatant clear, colorless liquid; it stands on a sheet of paper on which is written in pencil: "White lead direct from ore without producing first lead"!!

The Roessler-Edelmann Desilverizing Process shows samples of products which are interesting as illustrating a very important improvement of the Parkes process. In melting down zinc on a bath of softened base bullion, and subsequently stirring it in, a slight portion of both is very readily oxidized (see analyses in table, page 213), with the result that the zinc-silver alloy which forms becomes so intimately mixed with lead that the two can only be imperfectly separated by liquation. By the use of an alloy with 0.5 per cent. of aluminum, instead of pure zinc, the troublesome oxidation is almost entirely avoided and the elimination of lead from the crust greatly facilitated. The amount of zinc required to desilverize a given quantity of base bullion is proportionate to the silver it contains. It used to be necessary to desilverize in two, three, or four operations, as the zinc, whose solubility in lead increases with the temperature, could not be heated sufficiently without being oxidized. The advantage of the alloy is that it can be heated safely to the desired point without oxidizing, and thus can be dissolved by the lead in the quantity necessary to combine at once with all the silver. When the lead cools, its power to hold zinc in solution diminishes — *e.g.*, from 3 per cent. at 700°C to 0.6 per cent. at 400°C — the zinc-silver crust formed rises quickly to the surface, whence it is removed in the usual way. As it is nearly free from oxides, the bulk of the lead carried over in skimming is easily separated by liquation, and a crust results of the following composition:

Ag 20–40	Cu 1.5–2
Pb 3–4	Zn 76.5–54
	Al, Fe, As, Sb, traces

From it the zinc is separated by electrolysis, giving a very pure spelter:

Fe 0.0099	Pb 0.0341
Cu 0.0114	Zn 99.9446
	Ag, As, Sb, traces

and an anode-mud very rich in silver:

Ag 80–74	Cu 1.5–5
Pb 10–12	Zn 0.2–0.5
	As, Sb, Fe, traces

which can be readily converted into fine silver. Thus the process hastens the desilverization by requiring only one operation instead of two (as is the latest American practice if no gold crust is made); it furnishes a rich crust which, when electrolyzed, yields a higher percentage of zinc than is recovered by the usual retorting, and a residue which can be converted into fine silver quicker and with less loss than with the usual cupellation. Finally, as aluminum has no affinity for lead, it does not affect its properties in any way. The process is used at the refining works of Hoboken lez Anvers, Belgium, the annual production of which is 38,500 tons of lead and over 4,500,000 ounces of silver.

The exhibit consists of twelve samples:

1. Base bullion, from Mazarron, Spain.

2. Aluminum-zinc alloy, for desilverizing, the fracture of which is very fine-grained, while that of spelter shows the characteristic large faces.

3. Zinc-silver crust, as taken from the kettle and contaminated with lead, but free from oxide. This appears to have been slightly mushy when hot; it has a fine-grained fracture, a dull silver-gray color, and is free from the opalescent colors so common in the ordinary crusts.

4. A sample of alloy No. 3 has been melted down in a plumbago crucible and allowed to cool slowly, and the crucible and contents then sawed in two. The line of demarcation between alloy and liquated lead is perfect.

5. A small bar of liquated alloy, which has the appearance of desilverized lead not yet freed from the zinc it contains.

6. Liquated crust, cast into the form of an anode 4 by 14 inches and $\frac{1}{4}$ inch thick, ready to be electrolyzed. The surface is slightly

rough and bright colors are seen in a few places, showing that by repeated meltings a slight oxidation is liable to take place.

7. Represents the kathode, a thin piece of sheet zinc 11 by 19 inches.

8. Electro-deposited zinc. It is solid, has grape-like excrescences, and is of dull gray color.

The other exhibits, Nos. 9 to 12, electro-deposited zinc remelted, anode silver-mud, fine silver obtained from it, and refined lead, show no marked peculiarities.

THE TECHNICAL SCHOOL AND THE UNIVERSITY.[1]

By FRANCIS A. WALKER, LL.D., President of the Institute.

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In the August number of the *Atlantic Monthly* Professor Shaler has discussed the relations of academic and technical instruction in a way which brings the reader to some startling conclusions. So great are the advantages which a technical school is shown to derive from association with a university, so heavy the liabilities to narrowness and smallness of aim and purpose in the case of an independent school, that those of us who are connected with technical schools not attached to universities find ourselves put upon our defense; and this, too, under very serious charges. If any large part of Professor Shaler's position can be maintained, we are offenders against the cause of sound education. It is our duty at once to seek the sheltering arms of the nearest university; or, if there be none near enough to take charge of us, then we ought to disband and send our students to those who can do better by them. Professor Shaler does, indeed, admit that in a favorable environment a separate school may achieve a partial success; but he holds that this success is likely to be temporary, and at the best is attained through the sacrifice of important educational interests. In view of such a declaration by the dean of a technical school enjoying the protection and patronage of a great university, it is imperative that those who have to do with detached schools shall speak in their own behalf. The controversy is not of our seeking, and we must be pardoned if we speak with frankness on all the points at issue.

In the first place, it may not unfairly be said that, if the advantages of a connection with a university are so great, it is inexplicable that the effect of this should not more clearly appear in the history of that school which Professor Shaler mentions as the first of its class to be established, and which, through the whole extent of his article,

[1] Reprinted by special permission from the *Atlantic Monthly* for September, 1893.

he refers to in illustration of his principle. Harvard, as he says, has exercised an admirable hospitality towards many true and useful forms of learning. Its scientific department was founded under peculiarly fortunate conditions: a handsome endowment, a noble name, a cultivated community, association with the oldest college in the country, proximity to the richest manufacturing district. All these things seemed to assure success, yet the Lawrence School graduated twice as many pupils in the first half as it has in the last half of its history. Meanwhile, scores of technical schools have come into existence, often under circumstances most adverse, and with means painfully limited; have grown in numbers and increased in reputation throughout the general community; and have even come, in spite of prejudice, to command a high degree of respect and esteem from representatives of the old education. Does not this contrast fairly awaken incredulity as to Professor Shaler's argument, if indeed it does not create a strong presumption that he has overlooked some element, or elements, vital to the case?

The strongest instance in apparent corroboration of Professor Shaler's views is that afforded by the Sheffield School of New Haven. Here is a scientific school, giving a large amount of technical instruction, which was founded in connection with a university and has achieved eminent success. Yet to any one who knows the history of the Sheffield School, its experiences are directly in contravention of Professor Shaler's views, and indeed furnish the most important instance which could be cited against his position. Every Yale man knows that the Sheffield School grew up under the total neglect of the corporation of the college, which had nothing to do with the curriculum, and did absolutely nothing as to the selection of the teachers. In the eight and a half years while I was connected with the Sheffield School I but once saw the president of Yale in a meeting of its faculty, and that was by special appointment, with reference to the question whether the students should be required to attend morning prayers. So little had the school, in its early days, been considered by the corporation that when the Battell Chapel was erected, about 1873, no provision was made for giving the Sheffield undergraduates seats in it. Down to the accession of President Dwight the actual governing body was the faculty, under the admirable chairmanship of Professor George J. Brush. The faculty made out the budget, cut down their own salaries whenever that was necessary, apportioned the funds for

laboratory and general expenses, and selected the men who were to be appointed to positions which had become vacant or which it was deemed desirable to create. Not a single instance occurred where the choice of a professor was not solely and exclusively the work of the existing faculty. The appointment, in the legal sense, had of course to come from the corporation; but in no case did that body or the president take any initiative in the matter.

It was under conditions like these that the Sheffield Scientific School passed through the years during which its character was being molded and its scholarly traditions formed. I understand that Dr. Dwight, since his inauguration, has entered deeply into the questions relating to the Sheffield School and takes an active part in its councils. No more generous and comprehensive mind could be brought to the problems of any institution; and I am far from thinking that, with the traditions of the school already formed, the new régime will not be consistent with continued growth and prosperity; but I am fully convinced that Sheffield owes no small part of its brilliant success to the Cinderella-like abasement and neglect in which its work was begun and continued until the institution had passed from the gristle of youth into the solid bone of manhood.

So much for the Lawrence and Sheffield Schools as bearing on the issue which Professor Shaler has raised. Other technical schools have been founded in connection with universities, and some of them have done good work. But I know no reason for attributing to the School of Mines, in Columbia College, a higher character than that borne by the Stevens Institute, a detached school upon the opposite bank of the Hudson; while against the success attained by Sibley College, of Cornell University, may fairly be set the rolls of the alumni of the Rensselaer Polytechnic of Troy, the Rose Polytechnic of Terre Haute, and the Massachusetts Institute of Technology.

But let us leave the comparison of technical schools under the two systems, in order to examine the reasons, in the nature of the case, which are adduced as showing that connection with a university is not merely a favorable and fortunate condition, but a condition essential to the proper development and perfecting of every technical school. Professor Shaler's first plea has relation to the administration. He argues that a competent governing body is of the first importance in the career of any institution of learning; that it is very difficult to obtain a competent body; and that, therefore, when an able and suc-

cessful administration has been secured for a university, it must needs be of great service to a technical school to come under that rule, and thus be saved from the many possible and even probable disadvantages attendant upon an organization of its own board of trust. What Professor Shaler says regarding the vital importance of a strong but liberal and comprehensive government is true. Yet, when we are considering the question of the government of a technical school, it must be said that there is one element of even more importance than the business ability or intellectual power of its administrators. This is that they shall be deeply interested in the work; that they shall thoroughly believe in technical education; that they shall unaffectedly and profoundly respect the kind of man who is to teach in such a school, and the kind of pupil who is to receive the teaching. Possibly this is one of the elements which Professor Shaler has overlooked. Possibly in this respect there has been some failure among corporations or boards of trust composed of men bred in the old education, and having their standards and ideals of character and of conduct shaped by the influence of classical culture. Possibly this explains the comparative failure of some technical schools connected with universities. Professor Shaler admits that "still, to this day, the tendency has been to regard this department of instruction as something much below the university grade." Until that tendency shall have been completely arrested, and even reversed, may it not be better that this department of instruction shall be under the control and direction of its own devoted friends? For myself, I believe that scientific and technical education always encounters a grave risk when put out to nurse with representatives of classical culture.

Moreover, conceding, as has been done, the difficulty of securing an adequate governing body for any institution of learning, it may yet be said that this difficulty is not insuperable. The Institute of Technology has had among its trustees, to mention none of the living, men like Jacob Bigelow, Erastus B. Bigelow, John D. Philbrick, James B. Francis, George B. Emerson, J. Ingersoll Bowditch, Charles L. Flint — men fit to take part in the deliberations of senates or of universities, able in business, large of view, and faithful to every trust. If other technical schools, less fortunately situated, have suffered somewhat from the lack of liberal and comprehensive administration, it must be remembered that the same is true of all the smaller colleges of the land. If detached technical schools are to be given up on this

account, so must these. Yet who does not believe that, in spite of limited opportunities and means, our smaller colleges have done a truly glorious work for mind and manhood?

The second advantage, or group of advantages, which Professor Shaler attributes to a technical school under the patronage of a university may be said to relate to the students as distinguished from the governing body. The subject is necessarily somewhat vague. I am not sure that I rightly apprehend Professor Shaler's meaning at all points; but, so far as I can gather his views, he thinks the pupils derive a benefit in each of the following ways:

First, the student in such a school finds himself, in classes pursuing certain subjects essential to his course, in company with students not intending to adopt technical professions. These subjects may be, for example, chemistry, geology, physics, or mathematics — subjects which form the groundwork of technical courses, and which may also be pursued by college students as a part of their general training. Professor Shaler regards this association as a source of much advantage, applying to it the term "educative companionship." I confess that, unless it is to be presumed that the non-technical students are the better men or the better scholars, this idea appears to me very far fetched. The notion that because a young man is going, two or three years hence, to enter a law school, a medical school, or a divinity school, he therefore contributes some special flavor or savor to his class in chemistry, or physics, or geology, or mathematics today, is carrying the doctrine of final cause to an extreme.

There is only one assumption upon which this plea, conceding the equal merit of the students engaged, can have any validity. That assumption is often made by advocates of the old culture; but I am reluctant to believe that Professor Shaler could possibly adopt it, although he seems to do so when he speaks of "a truly academic atmosphere" as "one in which knowledge and a capacity for inquiry are valued for their own sake, and not measured by their uses in economic employment." The fling at technical studies as less "disinterested" than studies which are pursued without a direct object is one which has often been made in recent educational controversy; but those who use it have not seemed to me to show thereby their own superior liberality of mind. A young man who is faithfully seeking to qualify himself for an honorable and useful career in life may be disinterested in every sense in which that word can be used with approbation. Dis-

interestedness, in its true meaning, depends, not upon the studies pursued, not upon their immediate usefulness or uselessness, but upon the spirit in which the student enters upon and pursues his work. If there be intellectual honesty, if there be zeal in investigation, if there be delight in discovery, if there be fidelity to the truth as it is discerned, nothing more can be asked by the educator of highest aims. With such a student the useful applications of science distinctly add to the educational value of scientific study, inasmuch as they give a more direct object to his efforts and exertions, and heighten the pleasure he feels at each step of his scholarly progress.

The next advantage under this head which Professor Shaler finds in technical schools under the patronage of universities is in the opportunity afforded to the pupils to mingle some philosophical studies with those which are essential to their professional courses. In this connection it must be confessed that the faculties of many, perhaps of most, technical schools have made a mistake in not providing more so-called liberal studies. I agree fully with Professor Shaler in the opinion that such a union would conduce to ultimate professional success, as well as to the greater happiness of the man and the greater usefulness of the citizen. But the mistake referred to may be fairly attributed to the youth, and also, in some measure, to the poverty of the technical schools. That it is not in the nature of the case is shown by the curriculum of the Institute of Technology, where literary and philosophical studies extending over three years are required of all candidates for a degree. Of the Sheffield Scientific School, in this respect, it is enough to say that its students have for twenty-five years enjoyed the teaching of William D. Whitney and Thomas R. Lounsbury.

Another advantage which Professor Shaler discerns as attaching to professional schools under the patronage of universities is not easy of description or definition. It may, perhaps, be expressed by the single word "atmosphere." That there is something in it no one will deny; but the utmost benefit which the students of a technical school can derive from this source may easily be offset, many times over, by disadvantages arising from other sources. The history of Amherst, Dartmouth, and Williams, and of many other American colleges abundantly shows that the best atmosphere for a student is that which he himself brings to college with him in his own energy, fidelity, and scholarly zeal; that the next best atmosphere is that created by

learned, laborious, and high-minded teachers; the next best, that created by a body of devoted fellow students, all intent upon the work of preparation for life. Loafing in academic groves or browsing around among the varied foliage and herbage of a great university, pleasant as it may be, and well enough in its way, will have little effect upon the making of the man, in comparison with influences more serious, more pervasive, more penetrating.

That the students of technology throughout our country do, as a body, apply themselves to their tasks with wonderful energy and enthusiasm is a fact so familiar that it hardly needs to be adverted to here. The accession of such students to a great university would doubtless do much good to the university; but that the technical school would be better for the association may be questioned, in view of the multitude of distractions which beset ordinary student life and the frivolity of many of the interests which are there deemed of prime importance. On their part, young men do not greatly care to go to schools where they are not respected equally with the best; where all the praise and all the prizes go to others; where the stained fingers and rough clothes of the laboratory mark them as belonging to a class less distinguished than students of classics or philosophy. Professor Shaler remarks upon "ancient prejudices concerning the humble position of all mechanical employments." Is it quite certain that those prejudices are even yet so far worn out of the public mind that the students and teachers of technology may not feel more at ease by themselves, in schools devoted to their own purposes, than in schools where snobbishness makes odious comparisons, and where fashions are set in respect to student life, conduct, and dress which they have neither the means nor the inclination to imitate?

With much of what Professor Shaler says regarding the desirability of preparing young men for the technical professions more by inculcating principles and inspiring a zeal for investigation and a love of learning, and less by imparting mere information and teaching useful knacks and devices, I heartily concur. Too much cannot be said upon this theme. But the question does not necessarily concern the issue raised by Professor Shaler. More than one detached school has shown the liberality of sentiment, the comprehensiveness of view, and the high moral courage necessary to place and maintain technical education upon a lofty plane.

THE ORIGIN OF PARALLEL AND INTERSECTING JOINTS.

By W. O. CROSBY.

Received November 8, 1893.

SINCE the general abandonment of the contraction hypothesis as an adequate explanation of parallel and intersecting joints, two theories have claimed the attention of geologists — the torsion theory, so ably presented by Daubrée,[1] and the earthquake theory, proposed eleven years ago by the present writer.[2] The torsion theory is strongly supported by experiment, for the results obtained are certainly strikingly analogous to the phenomena observed in the natural ledges, and I have never doubted that it is a valid explanation admitting of a wide application.

As a rule, where the rocks are free, or nearly so, from shrinkage-cracks or joints due to contraction, and have not been exposed to severe crushing or shearing strains, they are traversed by two similar systems of nearly vertical joints crossing at large angles, and with usually no decisive indications that the two systems are not of the same age. Now Daubrée's experiments show that while simple plication yields a single system of longitudinal or strike joints, and the development of a transverse system would require a shifting of the axis of bending, torsion gives simultaneously two systems intersecting at large angles, but both oblique to the axis of torsion. These appear to exhibit all the normal characteristics of actual joints, including irregular examples and the not infrequent instances where one joint ends squarely against another without cutting it.

According to the earthquake theory, on the other hand, the different systems of joints dividing any given mass of rock were developed in succession, the normal direction of each system being parallel with

[1] Géologie Expérimentale, pp. 300–374.

[2] Proceedings Boston Society of Natural History, 22, 72–85.

the earth-waves producing them. It has been shown,[1] however, that this will be true of the second system only in case the direction of the second series of earth-waves is approximately at right angles to the first series, or they have a very high velocity of shock. For, while the first earthquake of sufficient energy to break the rocks will develop a system of joints at right angles to its path, the sheeting of the rocks thus resulting will cause the second system to cut the first at large angles regardless of the direction of the vibrations, in obedience to the principle that oblique strains would, if not developed instantaneously, be relieved by slipping along the joints of the first system and the formation of a series normal to them.

The fact that an occasional joint terminates against another without intersection is shown by experiment to be consistent with the torsion theory; but it is also readily explained by the earthquake theory, since each sheet determined by the first system of joints would, when subsequently exposed to endwise or oblique shocks, naturally break somewhat independently of the adjacent sheets. In fact, while the earthquake theory yields readily two systems of parallel joints crossing at large angles, it does not necessitate actual or mutual intersections; but the joints of the later system must, obviously, be often less continuous than those of the first system, while the torsion theory demands equality between the two systems in this respect. It is a legitimate corollary of the propositions in this paragraph that when one joint appears to cut and slip another of a different system, it is quite possibly the older rather than the younger; and the same caution is required in determining the relative ages of veins and dikes which may subsequently occupy or follow the joint-cracks.

The torsion theory calls for only two systems of joints, and the earthquake theory accounts with difficulty for more than two systems, although a third system is conceivable under this theory and in extreme cases, perhaps, a fourth system. The question may fairly be raised, however, as to whether in most cases the joints apparently referable to third and fourth systems are not better explained as the irregular examples which, as the experiments have shown, originate simultaneously with the regular rectangular systems. If strains developed as uniformly as possible in homogeneous plates of glass yield these irregular fractures, much more should they be expected in such a heterogeneous mass as the earth's crust.

[1] Proceedings Boston Society of Natural History, 22, 80; 23, 244.

The products of the two theories are, so far, strikingly similar, although the joints of unlike directions are simultaneous in the one case and successive in the other. The strongest contrast between the joints due to torsion and those due to vibratory movements arises from the fact that the torsional strains must, at least as a rule, be developed with extreme slowness, while the earthquake shock reaches its breaking intensity almost instantaneously. If the torsion were attributed to, that is, regarded as a phase or consequence of, the swift vibratory movement of the earthquake, then, of course, the two theories would be merged in one. In any other case the torsional strains must arise from the secular warping or deformation of the earth's crust. No argument is required to show that a strain that is suddenly developed must result in more regular fractures, and fractures less influenced by the structural inequalities of the medium, than one that is slowly developed; and in this direction lies the most serious objection to the torsion theory, the contrast between the two theories here being similar to that between the earthquake theory and the old contraction hypothesis. Strains developed under the conditions that obtain in the earth's crust, by simple plication, torsion, or shrinkage, must, in the nature of the case, approach the breaking point so gradually that, unless the rock is of an extremely homogeneous character, the yielding by rupture will be distributed over a considerable period of time. The rock gives way at the weakest point first, and throughout the breaking is influenced by every detail of texture and structure, the final result being far more irregular than under the instantaneous and alternating stresses that mark the passage of an earthquake.

In all cases, therefore, where the joint-structure of the rocks exhibits a high degree of regularity, we may fairly regard the torsion theory, at least in its present form, as inapplicable, as not affording an adequate explanation. This conclusion is particularly safe in those cases where jointing of exceptional regularity is observed in rocks of coarse and irregular texture. It is certainly well-nigh inconceivable that the remarkably plane and regular jointing of the Roxbury pudding stone and the coarse Newport conglomerate, in which the hard pebbles of quartzite, felsite, and granite, and the yielding matrix have been neatly divided as by one swift stroke of some Titan's sword, can be the product of slowly developed torsional strains. The torsion theory also fails most signally to explain the very perfect and regular parallel and intersecting joints sometimes observed in unconsolidated

deposits, as in the Miocene clays of Virginia[1] and even in the glacial clays of New England.

The preceding paragraphs may be summarized as follows: A single system of joints, dividing the rock into sheets but not into blocks, appears to be best explained by earthquake vibrations, or by simple plication if not of a high degree of regularity. Two systems of unlike character are also best explained by the earthquake theory, but two systems of similar character may be referred to the torsion theory, unless, again, they exhibit the regularity indicative of instantaneous stresses, while joints of even moderate regularity are not satisfactorily explained by torsion if occurring in incoherent deposits or rocks of irregular structure.

Jointing is the most universal of rock structures, and with respect to the universality of the agents there is little to choose between the two theories under discussion. The observations of Professor Niles[2] and others confirm the belief, which, no doubt, exists independently of specific facts in the minds of most geologists, that the relatively superficial strata of the earth's crust are very generally, if not almost everywhere, in a state of strain — compressive, tensile, or torsional; and it will be readily conceded that probably all parts of the earth's crust have been traversed by severe earthquakes.

It has occurred to me, however, during the past year, while preparing a set of lecture notes on joint-structure, that some of the perplexities of the subject would be removed by combining the torsion and vibration theories. It is a familiar fact that when a body is in a state of strain a shock or jar will often precipitate the yielding or collapse. If the strain is near the breaking intensity, a very slight shock is sufficient; and in such a case the directions of the fractures will be determined wholly by the preëxisting strain and not in any sensible degree by the vibrations. The function of the latter is simply to bring the strain *instantly* to the breaking intensity and thus insure straight and regular fractures along the predetermined lines. Torsion yields simultaneously two rectangular systems of fractures, while the earthquake vibrations produce plane and regular fractures in almost all kinds of rocks. In other words, if coöperating, torsion would naturally determine the directions of the fractures, and the vibrations the time and

[1] Proceedings Boston Society of Natural History, 23, 245.
[2] Proceedings Boston Society of Natural History, 18, 272.

mode of breaking. Simply conceive, then, that, as must often happen, while a torsional or plicating strain is being slowly developed in the rocks and is yet considerably below the breaking intensity, they are traversed by an earthquake of moderate severity. Although the shock is insufficient in itself to break the rocks, it will precipitate the breaking that is imminent through bending. Simple plication would then yield one system of regular joints, and torsion two systems. The main point is that the torsional strain, instead of continuing to develop slowly and reaching the breaking intensity by insensible degrees, culminates under the influence of the shock instantaneously, accomplishing its work, at last, swiftly instead of sluggishly. The vibrations are merely the last straw, or the finger that pulls the trigger and releases the accumulated energy.

I have repeated Daubrée's experiments with sheets of glass, obtaining similar results; and have also modified them, to note the effect of a sudden shock. Strips of glass 24 inches long and from 3 to 5 inches wide were tested in a horizontal position on an ordinary table, one end being held by a stationary clamp, while the other end was clamped by the lever which was attached by a hinge in the axis of torsion to a fixed support or fulcrum. The lever was so long that it could be weighted, and the torsional strain in the glass thus carefully regulated. The shock was applied at first by striking the table — to which the apparatus was firmly fastened — with a hammer, the glass being entirely free from the table except at its extremities. Before applying the shock, however, the lever was first weighted until it seemed that the strain in the glass must be near the breaking point; and then the weight was materially diminished to make sure that the glass was not dangerously near collapsing before the passage of the vibrations. A smart blow with the hammer then precipitates the breaking, and the result is similar to that obtained by torsion alone, except that the fractures are likely to be fewer if the torsional strain is not near its maximum. The direction of the vibrations makes, apparently, but little difference; and in every trial two rectangular systems of fractures, making equal angles with the axis of torsion, were obtained. The breaking or jointing of the glass was most regular and perfect when a sharp blow with a light hammer directly upon the end of the glass itself sent vibrations through it bearing some resemblance to an actual earthquake. When the torsional strain is slight, strong vibrations are required to precipitate the breaking, and the fractures are

irregular and mainly transverse, tending to cut the axis of torsion at angles of ninety degrees instead of forty-five degrees. But if the torsional strain is great, a very slight shock suffices, and the result is, with glass, indistinguishable from that obtained by torsion alone. To those who accept this explanation of parallel and intersecting joints, the more concise expression, rectangular joints, may seem equally appropriate and descriptive.

One important consideration affecting the validity of the earthquake theory that appears to have been overlooked hitherto is that, just as a fountain cannot rise above its source, and the brightness of sunlight cannot exceed that of the solar photosphere, so the energy of an earthquake must always be greatest at its focus. Most earthquakes, except possibly in volcanic districts, may be assumed to originate in the formation of a fissure by tensile or shearing strain, or in the slipping of the rocks along a preëxisting fissure, that is, in the formation of a fault. The rupture or movement in which the earthwaves take their rise will occur just so soon as the slowly accumulating strain overcomes the cohesion of the rocks or the friction of the opposing walls. In other words, the energy of the earthquake is barely sufficient at its source to break the rocks. But as the vibrations spread from the source, this energy is rapidly dissipated. Hence, we can scarcely expect that the earthquake, unaided by strains due to other causes, will break the rocks, except in the immediate vicinity of the focus, unless, indeed, the vibrations chance to pass into some formation that is much less elastic and more easily broken than the one in which they originate, as when the shock emerges from the earth and enters the walls of buildings. The idea, therefore, that an earthquake shock will give rise to a series of fractures parallel with the initial rupture — a system of joints — is essentially untenable, or at least does not admit of general application. Torsion and plication, on the other hand, although equal to the task of breaking the rocks, are powerless to produce the highly regular fractures observed in many formations. The arguments thus point very distinctly to a fusion or coöperation of the two causes. The parallel joints observed in unconsolidated clays may, apparently, be best explained by the passage of strong vibrations into the clay from adjacent or underlying hard rocks, the influence of torsion being reduced to a minimum here.

When performing Daubrée's experiment — breaking strips of glass by simple torsion — for the first time, I was astonished, since no pains

were taken to obtain strips of uniform width, and each must have possessed a weakest line, to find that the breaking was not localized but quite uniformly distributed, the glass being shivered from end to end, in some cases into hundreds of rectangular fragments. I am satisfied, upon reflection, that the only rational explanation of this phenomenon is that the glass does actually break first at its weakest point, and so suddenly, being a highly elastic substance, that the resulting shock or jar spreading swiftly toward either end of the sheet precipitates the breaking through its entire length. Applying this explanation to the earth's crust, it is seen that earthquake vibrations arising independently of the torsional strains with which they coöperate are not strictly necessary to the satisfactory working of the composite theory here proposed.

Plain indications are not wanting that the joint-structure of the rocks is developed, as a rule, very early in their history. That is sufficiently obvious for the contraction joints, including the sun-cracks in clay and the columnar jointing of eruptive rocks, and for the parallel and intersecting joints of the Quaternary and Tertiary clays and marls. In the older stratified rocks, the dikes and veins, where occurring, usually conform in direction with the joints of this class. This is conspicuously the case in the Boston Basin, the numerous dikes traversing the beds of conglomerate and slate showing a close correspondence in trend and hade with the joint-planes. The dikes must be later than the joints, and yet we have reason to believe that the dikes themselves are, geologically speaking, nearly as old as the strata which they intersect. As soon as the sediments are sufficiently hardened to make joint-cracks a possibility, they are broken or jointed by the first torsional or vibratory strains of adequate intensity to which they are exposed; and ever after similar strains, unless of unusual intensity, are relieved by slipping along the existing fractures, which are thereby, in many cases we may suppose, kept open and prevented from healing by slow cementation, and are converted into minor faults with the attendant slickenside phenomena.

THE DETERMINATION OF THE ELECTROLYTIC DISSOCIATION OF SALTS BY SOLUBILITY EXPERIMENTS.

By ARTHUR A. NOYES, Ph.D.

Received November 10, 1893.

In a former article[1] on this subject I showed that the solubility effect and the electrical conductivity of salts lead to different values of the dissociation, and concluded that those deduced from solubility experiments are probably the correct ones. Arrhenius,[2] however, has lately attempted to prove that the solubility effect is a property entirely unfitted for the determination of dissociation, as different values are obtained for the same salt according to the solubility of the difficultly soluble salt used in connection with it.

The general question of the relative reliability of the conductivity and solubility values can only be decided satisfactorily with the help of further solubility experiments. I shall therefore here confine myself to pointing out the errors in Arrhenius' treatment of his results. This consists in the assumption, on which all his calculations rest, that all binary salts have the same dissociation constants. The justification for this he finds first in the fact that I made the same assumption in a certain case, and second, in the fact that the electrical conductivity indicates an equal dissociation of the salts in question. My assumption had reference to the equal dissociation of the chlorides of thallium and the alkalies. The reasons for it were not conclusive, and I distinctly stated that it was to be regarded only as probable, and that, if at any time more exact knowledge of the dissociation of thallous chloride was obtained, the calculated values of the dissociation could be corrected correspondingly.

Such an assumption would certainly not have been made if my experiments, like those of Arrhenius, had furnished a direct proof of

[1] Technology Quarterly, 4, 259.

[2] Zeitschrift für physikalische Chemie, 11, 391.

the contrary. Consider his results on the influence of silver nitrate and silver acetate on the solubility of silver valerate, reproduced in the following table:

Added quantity.	Solubility in presence of silver acetate.	Solubility in presence of silver nitrate.
0	0.0094	0.0094
0.0067	0.0070	0.0068
0.0134	0.0057	0.0051
0.0268	0.0037	0.0031

The nitrate evidently causes a considerably greater reduction of the solubility than the acetate, whence follows without any calculation that the former salt is more dissociated. The relative effect of these two salts on the solubility of silver butyrate also differs in the same way[1] — an independent proof of their unequal dissociation. Nevertheless, Arrhenius calculates later their dissociation under assumption of equality, and obtains, of course, utterly false values. The same is true of the other experiments of Arrhenius; that is to say, the influence of two different salts on the solubility of a third is in almost all cases different. The following general relations seem to hold: of the investigated salts silver nitrate is the most, and the silver salts of the organic acids are the least, dissociated, while the sodium salts of the organic acids occupy an intermediate position. The values of the dissociation calculated by Arrhenius are therefore all or mostly inexact, and the conclusions based upon them lose their significance.

According to Arrhenius, his calculations show, "with the greatest possible clearness, that widely different values of the dissociation are obtained for the same salt; for example, silver nitrate, according as the difficultly soluble salt used in connection with it is more or less soluble. And this variation takes place with a very distinctly marked regularity; namely, the dissociation comes out smaller the less the solubility of the salt used." It is of interest to show that this con-

[1] This is not at once evident from the numbers, for the added quantities of the two salts were different in this case. It is seen, however, from a graphical representation of the results, or also from the difference of the dissociation values calculated by Arrhenius.

clusion is only a consequence of the false assumption of *equal* dissociation constants.

The calculation of Arrhenius was made by means of the formula:

$$a = \frac{m_0 - m}{x}\left(1 + \sqrt{1 + \frac{x}{m}}\right)$$

which, however, for the case of unequal dissociation-constants becomes:

$$a = \frac{m_0 - m}{x\,\frac{a_1}{a}}\left(1 + \sqrt{1 + \frac{xa_1}{ma}}\right)$$

(m_0 is the solubility in pure water, m that in presence of the quantity x of the added salt; a is the dissociation of the original, and a_1 that of the added salt).

If now the dissociation constant of the added salt is greater than that of the salt with which the solution is saturated, as is probable from what was said above, then a_1 is greater than a and the calculation by the first formula gives too large values of the dissociation; and moreover, as the ratio $a_1 : a$ increases with increasing concentration, the dissociation would be thus found so much greater the greater the solubility of the difficultly soluble salt used, exactly as Arrhenius found. His experiments, therefore, prove nothing against the solubility method of determining dissociation; they do indeed show the inadmissibility of the assumption that all binary salts are equally dissociated.

The conclusion of Arrhenius in regard to the equal dissociation of the various salts based on the electrical conductivity is plainly a *petitio principii.* From the point of view of the solubility method, it is only a further proof against the applicability of conductivity for the accurate determination of the dissociation of salts.

Some other points of Arrhenius' article remain to be considered. He attributes a much greater significance to my suggestion of the conductivity of the water itself as a possible explanation of the too great conductivity of salts than I did myself. I am now convinced that a dissociation of the water great enough to explain the deviations is not possible.

Arrhenius' conception of the solubility equilibrium appears to me to be incorrect; for he considers the solubility to be dependent only on what is present in the solution, not as a phenomenon of equilib-

rium between the solid salt and the solution.[1] He says, "The slight solubility of a difficultly soluble salt arises only from the fact that the undissociated part of it is insoluble; for in the case of silver acetate, for example, we know that the dissociated parts (the ions) are in the highest degree soluble, since concentrated solutions of silver nitrate and potassium acetate contain very considerable quantities of Ag and $C_2H_3O_2$ ions." But how can we speak of the solubility of an ion, when ions do not exist except in solution? The true question is, what is it in the solution which holds the equilibrium with the solid salt? Is it the undissociated portion, or is it the ions? At present there is no means of deciding this question. It is probable, however, that both take part, and in the case of difficultly soluble salts, where the undissociated portion is very small, that the equilibrium is principally maintained by the ions. And this was the form in which Nernst[2] originally expressed his theory.

In conclusion, I will only further remark that the decision between solubility effect and electrical conductivity as methods for the determination of the dissociation of salts is to be reached in the way Arrhenius has attempted it; that is, it must be shown that independent solubility experiments with different salts lead to the same value of the dissociation of a given salt. The experiments must, however, be so chosen that no assumption in regard to their equal dissociation is necessary. I hope to be able later to publish the results of some experiments of this kind.

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[1] Ostwald has repeatedly pointed out this common error. His Lehrbuch, 1 (2d ed.), 1036, 1038; 2 (1st ed.), 644.

[2] Zeitschrift für physikalische Chemie, 4, 379.

ON WURTZ'S METHOD FOR THE DIFFERENTIATION OF BACILLUS TYPHI ABDOMINALIS FROM BACILLUS COLI COMMUNIS, AND ITS APPLICATION TO THE EXAMINATION OF CONTAMINATED DRINKING WATER.

By ALBERT P. MATHEWS, S.B., Assistant in Biology.

Whatever its ætiological significance may be, it is now admitted on all sides that the bacillus which is generally regarded as the specific organism of typhoid fever bears a remarkable resemblance to the common fæces bacillus. The practical importance of this resemblance is very great, because it renders difficult the search for the specific germs of the disease in the bowel discharges; and for the same reason the examination of suspected milk or water possibly contaminated by such discharges becomes a matter involving much uncertainty. So great is the similarity of the common fæces bacillus to the Eberth bacillus that some bacteriologists have believed that the two forms are only unstable varieties of one and the same species, while others, after prolonged investigation, have concluded that they are totally distinct.

Under the general direction of Professor Sedgwick, Biologist of the State Board of Health of Massachusetts, studies have been made upon the various methods proposed for the differentiation of the two forms, of which one series has already been published.[1]

In the course of these studies it was suggested to me by Professor Sedgwick that I should examine a method then just published, namely, that of R. Wurtz.[2] Before doing so, however, I had examined the methods of Chantemesse and Widal,[3] Vincent,[4] Uffelman,[5]

[1] Boston Medical and Surgical Journal, September 1, 1892. State Board of Health of Massachusetts, Report for 1891, page 637.

[2] Arch. de Med. Exp. Tome IV, No. 1, page 85.

[3] Gazette des hospiteaux, 1887, page 202.

[4] Comptes rendus hebdomadaires des séances de la Société de biologie 1890, No. 5.

[5] Berliner klinische Wochenschrift, 1891, N. 35, S. 857.

and others. Not finding these in all respects satisfactory, I proceeded to the method of Wurtz, which, after prolonged investigation, I have found to be eminently practicable, and one of the most valuable means of separating the Eberth bacillus from the fæces bacillus which has yet been proposed. Moreover, it is a method of great service in the examination of excreta, suspected drinking water, milk, etc.

The results obtained by this method have been so satisfactory and so striking that it was exhibited by us at the annual meeting of the Massachusetts Medical Society in June, 1892, where it attracted much attention. It was also made the basis of a special piece of work submitted by me as a thesis for the bachelor's degree of the Massachusetts Institute of Technology in May, 1892. Since that time I have used the method repeatedly in the examination of waters for the State Board of Health as well as in other work; and, as I am constantly more impressed with its value and its importance, I shall in this paper describe it in detail and indicate some of its applications and results. I do this the more freely because the value of the method does not seem to have been apprehended either in Europe or in America, although, as I have intimated, it may often be of great service to working bacteriologists.

Wurtz's method consists in cultivating the organisms upon ordinary nutrient agar to which has been added a certain amount of lactose and an aqueous solution of blue litmus. Wurtz's culture medium, then, may be described as *litmus-lactose-agar*. Upon this the Eberth bacillus grows luxuriantly, producing light blue colonies of no very characteristic form. *B. coli communis* on the same medium produces colonies of similar shape, but which soon become pinkish and finally bright red. The sterile plate of litmus-lactose-agar has a weak, but distinct, blue color. If upon this two parallel stroke cultures be made with platinum needles, from a half inch to an inch apart, one from a culture of the fæces bacillus, and the other from a culture of the so-called typhoid bacillus, after twelve to twenty hours in the incubator at 37.5°C. a most striking and beautiful result is obtained. The path of the needle from the typhoid culture exhibits a rich crop of a light blue color, while the inoculation line of the needle from the other culture shows a crop which is completely red. The plate originally uniformly bluish is now one half blue and the other half red.

So precise and constant is this result that it greatly simplifies the problem of the separation of *B. coli communis* from *B. typhi abdominalis*, for there has been no method hitherto suggested, as far as I am aware, which, while being of the greatest accuracy, so visibly and forcibly illustrates the difference between these two organisms.

In what follows I shall attempt to show that its ease of application, the rapidity of its action, and the visibility of its results make it a method of uncommon interest to the physician and the sanitarian. To the former it suggests the ultimate possibility of the diagnosis of typhoid fever in the earliest stages of the disease; to the latter it offers at once a novel and a simple aid in the detection of the so-called specific organism of typhoid fever in excreta, sewage, milk, or drinking water.

The method was hinted at by Chantemesse and Widal, who added lactose to bouillon, but was perfected by Wurtz, who added the lactose to solid media and then ingeniously introduced blue litmus, making use of the apparently constant difference in function of the two germs as exhibited by their reaction to the sugars; and is in detail as follows.

To a known amount of nutrient gelatine, agar, or bouillon, there is added two or three per cent. by weight of lactose. The mass is then tubed and sterilized, and just before using it an aqueous solution of blue litmus is added sufficient to give to the medium a decided blue color. The litmus is a strong aqueous solution sterilized separately, as I have found, as Wurtz states, that in heating it in contact with the organic matter of the media it loses its color. The medium, before the addition of the lactose, is made alkaline to such a degree that one cubic centimeter of it shall be equivalent to one tenth of a cubic centimeter of a twentieth-normal solution of sulphuric acid, phenol-phtalein being the indicator.

In such a medium *B. coli communis*, fermenting the lactose, produces an abundant acid. The Eberth bacillus, on the other hand, according to Peré[1], leaves the alkalinity unaltered. My own experience, however, has been that *B. typhi abdominalis* has invariably rendered the medium more alkaline, as the plate becomes of a deeper blue color after the growth upon it of the typhoid bacillus than it

[1] Annales de l'Institut Pasteur, Tome 6, No. 7, page 512.

was at the beginning. Wurtz recommends that the two species be sown in lines on the surface of a plate prepared after this method. I have found, however, that the plate simply planted in the ordinary manner affords an important means of distinguishing the colonies. It is impossible to emphasize too strongly the striking demonstration of the difference between these two forms which this method affords.

It was very encouraging, moreover, to find that never at any time, in the course of hundreds of tests of the method with new and old cultures of the different forms, cultures taken directly from the human spleen and those which had come some time ago from the laboratories of Chantemesse and of Prudden, respectively, has there been the slightest tendency observed for the *B. typhi abdominalis* to redden the litmus, and never have I failed to secure a coloration with *B. coli communis*, though it does appear that the fermentation is more rapid with a sample of *B. coli communis* taken directly from the fæces than with a culture recovered from water and thereafter grown for many generations in the laboratory.

By the courtesy of Dr. W. T. Councilman, Pathologist of the Boston City Hospital, I was given an opportunity to apply the method to the examination of the spleen and mesenteric glands of a typical case of typhoid fever. Numerous cultures from these organs were made with all precautions, and the result was very satisfactory. From the spleen rich crops of Eberth bacilli were obtained answering perfectly to all the recognized differential tests. These colonies left entirely blue the plates of litmus-lactose-agar incubated at 37.5°, and proved to be pure cultures of the Eberth bacillus. The cultures from the mesenteric glands, on the other hand, showed the large majority of the colonies to be bright red, and subsequent examination proved them to be *B. coli communis*. The blue colonies from these cultures as far as examined proved to be Eberth bacilli. As a means of obtaining fresh cultures of Eberth bacilli no method could be simpler than this one, inasmuch as it appears to be only necessary to make a single Wurtz-agar plate culture of a typhoid spleen, to select the blue colonies found thereon and then submit them to the recognized tests with milk, the Smith fermentation tube, etc.[1]

[1] See G. W. Fuller, "Differentiation of the Bacillus of Typhoid Fever," Boston Medical and Surgical Journal, September, 1892.

APPLICATION OF THE METHOD OF WURTZ TO THE EXAMINATION OF WATER.

Valuable as the method is for the ready distinguishing of the two species and as demonstrating a functional difference between them, it is equally valuable in its application to sanitary bacteriology. Every bacteriologist knows the difficulties hitherto experienced in searching for the typhoid bacillus in a suspected water. There is danger, if gelatine be used, that the plate will be liquefied by the early development of a large number of liquefying colonies. This difficulty Chantemesse and Widal attempted to overcome by the use of carbolic acid. If, on the other hand, agar is used and a heat differentiation is obtained, the colony of typhoid loses all the characteristics it would have had on the gelatine plate. The difficulty has been that although the gelatine might not liquefy, yet there are many species of water bacteria which upon this medium mimic its growth completely; in the second place the form and appearance of the Eberth-Gaffky colony itself is by no means constant, varying under different conditions not well understood; and in the third place the time taken for the identification of the germ is so great as to make this method of little service in practical diagnosis. The method of Wurtz overcomes these difficulties.

The following experiments have been carried on in the bacteriological laboratory of the Massachusetts Institute of Technology, and I am much indebted to Dr. Sedgwick for his kindly interest in the work as well as for much helpful criticism.

In its application to the investigation of water suspected to contain the Eberth-Gaffky bacillus, I have attempted to determine the exact value of the method as compared with the ordinary gelatine method hitherto employed. The mode of procedure was as follows: To the tubes of agar prepared as noted above and cooled after the introduction of the litmus to a point but little above the coagulating temperature of the agar, a cubic centimeter of the water was added; the mixture was then plated and placed in the incubator for fourteen hours. At the end of that time it was generally possible to distinguish easily between the red and blue colonies. The blue and doubtful ones were transferred to the Smith tube and to the milk, and these returned to the incubator where, in seventeen hours more, it was possible to discard the large majority

as producing a gas in the one or coagulating the other. If any doubt still existed transfers were made to the nitrate tubes, potato, gelatine, and bouillon.

Following are cited a number of experiments in which the method was applied to the examination of different ground and surface waters. Unfortunately, when the colonies were red I did not, at all times, take the trouble to note the exact number on the plate, so that, as will be noticed, the two columns which show the ratio of red to blue colonies on the agar plate are incomplete. At the time of making the examination I was interested more especially in the examination of the water to determine the absence or presence of typhoid colonies, and only later concluded to incorporate the results in the present paper to illustrate the value of the heat differentiation employed. The results shown in the following table are drawn from a large number of sources, chiefly in Massachusetts, and the names of the particular water supplies are omitted :

Number of Experiment.	Source of Sample.	Colonies of Bacteria per c.c. Gelatine. 20°C.	Lactose-litmus-agar plate. 37.5°. C.		
			Colonies of Bacteria per c.c.	Blue Colonies.	Red Colonies.
1.	Driven well	3835	3 colonies on 6 plates.	0	3
2.	Driven well	Liquefied.	13	9	4
3.	Well	Liquefied.	2 colonies on 4 plates.	0	2
4.	Well	....	8	4	4
5.	A city water	80	19	16	3
6.	Well	725	27	9	18
7.	Spring	....	102	....	....
8.	Spring	....	440	....	....
9.	Spring	....	110	13	97
10.	Spring	....	250	....	....
11.	Spring	....	1	1	0
12.	Spring	....	7	4	3
13.	A town supply . . .	....	3	1	2
14.	Well	3650	14	0	11
15.	Spring	5125	215	....	....
16.	Well	3143	1	1	0
17.	A city water	Liquefied.	425	....	....
18.	Well	Liquefied.	175	....	....
19.	Pond	75	115	....	....
20.	Pond	175	145	81	64
21.	Pond	179	120	80	40
22.	Brook	212	44	34	10
23.	Pond	153	142	55	87
24.	Well	51	12	6	6
25.	Filtered river water .	4	10	....	....
26.	River water	159	45	....	....
27.	Filtered river water .	25	38	....	....
28.	Pond	200	22	22	0
29.	Pond	225	22	....	....
30.	Brook	450	213	....	....

Number of Experiment.	Source of Sample.	Colonies of Bacteria per c.c. Gelatine. 20°C.	Bacteria per c.c. Lactose-litmus-agar plate. 37.5°C.	Blue Colonies.	Red Colonies.
31.	Reservoir	180	100	....	....
32.	Reservoir	14	18	....	....
33.	Pond	798	178	....	....
34.	Pond	235	121	121	0
35.	Pond	100	47	47	0
36.	Reservoir	93	63	....	....
37.	Pond	300	132	....	....
38.	Pond	1701	248	....	....
39.	Pond	170	95	....	....
40.	Pond	121	60	....	....
41.	Reservoir	71	8	....	....
42.	Reservoir	320	60	....	....
43.	Reservoir	240	11	....	....
44.	Tap	43	2	....	....
45.	Pond	254	35	33	2
46.	Pond	119	9	....	....
47.	Pond	229	145	....	....
48.	Pond	18	12	....	....
49.	Tap	119	50	....	....
50.	Pond	850	40	....	....
51.	Pond	237	77	....	....
52.	Pond	300	202	....	....
53.	Pond	91	49	....	....
54.	Well	25	1	....	....
55.	Well	79	3	....	....
56.	Well	1	0	....	....
57.	Well	6	6	....	....
58.	Tap	30	0	....	....
59.	Well	3649	17	2	15

SUMMARY.

Source of waters examined.	Average number of colonies per c.c. Gelatine. 20°C.	Average number of colonies per c.c. Wurtz-agar. 37.5°C.
Wells and springs	1664	28
Reservoirs	153	43
Ponds	296	95
Taps	242	24
Streams	273	101

It was shown by Hazen and White (Boston Medical and Surgical Journal, April 15, 1891) that the agar plate at 37.5°C. offers a valuable practical aid in the bacteriological examination of water. In this connection the following results are especially interesting.

HEAT AND AGAR DIFFERENTIATION (AGAR PLATES).

Considering the gelatine plates as representing all the bacteria present in one cubic centimeter of the water examined, the following table shows percentages of the numbers of bacteria present in the original sample which did not grow on the agar plate at 37.5°:

	Ground Waters.	Reservoirs.	Ponds.	Streams.	Taps.	Surface Waters. Average.
Per cent. of Inhibition . .	92	71	64	63	70	67

LACTOSE–LITMUS DIFFERENTIATION (WURTZ'S METHOD).

a. Ground Waters.

Total number of blue colonies, 49. Average per cc., 4. Total number of red colonies, 153. Average per cc., 13.

Red colonies found in ground waters, 76 per cent. of the whole number growing at 37.5°C.

b. Surface Waters.

Total blue colonies, 473. Average per cc., 59. Total red colonies, 203. Average per cc., 25. Red colonies in surface waters, 30 per cent. of all growing at 37.5°C.

Although conclusions drawn from so few experiments cannot be expected to be more than approximate, I consider the figures as

highly instructive. The results of many experiments have been most encouraging. In some instances the gelatine plate has liquefied in two days in the presence of thousands of water bacteria, while the agar plate has shown only one or two colonies, red or blue, as the case may be. As far as my actual experiments go, an inspection of the numerical result permits us to draw the following conclusions:

1. *The heat and agar differentiation* secured by growing agar plates at body temperature prevents the development of 92 per cent. of all bacteria in ground waters; 63 per cent. of all bacteria in streams; 64 per cent. of bacteria in ponds; 71 per cent. of bacteria in reservoirs; and 70 per cent. of bacteria in tap water which has run through iron mains for some distance; or, in other words, we are able by the agar plate at 37.5° to throw out at once as not being *B. typhi abdominalis* 92 per cent. of all the bacteria commonly found in ground waters, and 67 per cent. of all bacteria usually met with in surface waters. Presumably the higher temperature of the latter class of waters prevents the differentiation from being as complete for them as for the former. By a number of tests made since, in the winter, I am convinced that the results already quoted, obtained as they were during the latter part of a very hot summer, represent the minimum of differentiation, and that had my tests been made in the winter the heat differentiation might have been as efficacious for surface waters as for ground waters.

2. *The lactose-litmus differentiation* (*Wurtz's Method*) enables us to distinguish from the Eberth bacillus 76 per cent. of those bacteria found in ground waters but growing at the body temperature, these producing acid and coloring the plate red; and at the end of seventeen hours in the incubator 30 per cent. of all those bacteria found in surface waters, but growing at the body temperature, may be as readily separated from the typhoid.

3. There is, of course, a still further reduction of probable colonies of *B. typhi abdominalis* possible, as one is able by a cursory inspection of the blue colonies on the plate to discard many which have a peculiarly and markedly non-typhoid-like growth. As for the few colonies which may be left, these are readily transferred to the Smith tube, to milk, and to gelatine; and as a rule most of them will be thrown out either because they produce a gas or grow only in the open arm of the bent tube, or because they coagulate milk.

On the other hand, there are certain disadvantages in the method. If a motile bacillus be present it is very apt, by means of the water of condensation, to spread over the surface of the agar plate. This may be avoided to some extent by allowing the agar to cool to the lowest degree possible before introducing the water, and by permitting the plate to solidify thoroughly before placing it in the incubator. It is always advisable, however, to plant a great many plates of each sample of water, by that means increasing the chances of finding any Eberth bacilli present.

In conclusion I may remark that since the above was written further experience has only served to confirm the favorable judgment already formed. In its application to the examination of a suspected water supply it is invaluable, particularly if used in the fall, winter, or early spring, for at this season of the year the heat differentiation is most effectual. The quickness of its action and the advantage of using a medium not liquefiable yet enabling us at once to distinguish the Eberth bacillus from many other forms closely resembling it in their growth on gelatine, render the method a particularly useful one to the working bacteriologist.

PRELIMINARY NOTE ON A METHOD FOR THE HARMONIC ANALYSIS OF ALTERNATING CURRENTS.

BY FRANK A. LAWS, S.B.

Received November 29, 1893.

THE "Instantaneous contact" method of mapping the forms of the E. M. F. and current waves in alternating current circuits, which was first devised by Joubert, has been so useful in giving a clear understanding of the phenomena occurring in such circuits that I venture to give an outline of a method for the harmonic analysis of such current curves. It is not thought that this method will displace the direct and simpler method of Joubert, but the results given by it would be of considerable interest, for instance in the investigation of the effect of the introduction of iron into coils traversed by alternating currents.

According to the analysis of Fourier, any function whatever, subject to certain conditions, which are fulfilled by the current function, may be expressed as the sum of a series of sine and cosine terms, or

$$C = \begin{cases} A_1 \sin Pt + A_2 \sin 2Pt + A_3 \sin 3Pt + \dots \\ + B_0 + B_1 \cos Pt + B_2 \cos 2Pt + B_3 \cos 3Pt + \dots \end{cases}$$

where

$$A_m = \frac{1}{\pi} \int_{-\pi}^{+\pi} f(Pt) \sin m\,(Pt)\, d\,(Pt)$$

$$B_m = \frac{1}{\pi} \int_{-\pi}^{+\pi} f(Pt) \cos m\,(Pt)\, d\,(Pt)$$

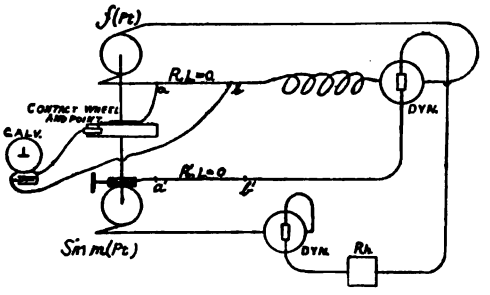
It is seen that A_m and B_m can be made to depend on the average value between $+\pi$ and $-\pi$ of the product of the unknown current and a sine current of periodicity m P, the zero values being coincident and the phase relation definite but capable of variation and measurement. Electrically speaking, this means that the deflection of an electro-dynamometer, through one coil of which flows the sinusoidal current, while the current subject to analysis flows through the other, will be proportional to either A_m or B_m, accordingly as the currents are in step or out of step by 90°.

At any instant the force acting on the movable coil will be $KK_s f(Pt) \sin m\,Pt$, where K is an instrumental constant and K_s is the maximum value of the sine current. The function of the dynamometer is to take the required integral

$$D_m = \frac{KK_s}{2\pi} \int_{-\pi}^{+\pi} f(Pt) \sin m(Pt)\, d(Pt) = \frac{KK_s}{2} A_m.$$

$A_m = \frac{2D_m}{KK_s}$, if dynamos are in step, and similarly for B_m when the sine current has been set forward 90° in phase, $B_m = \frac{2D^1_m}{KK_s}$. K_s is determined from the reading of a second dynamometer.

To put the dynamos in step, apparatus may be arranged as in the following sketch.



The procedure would be first to place terminals at *a*, *b*; adjust contact point until no deflection is obtained on galvanometer; change to a^1, b^1; adjust the phase of the sine current until no deflection is obtained. The two zero points are now coincident, and the apparatus adjusted for finding A_m. A different procedure may be adopted which will reduce the number of settings necessary for any analysis by one half.

When A_m and B_m are combined, the expression for C is

$$C = B_0 + \sqrt{A_1^2 + B_1^2} \sin(Pt + \phi_1) + \sqrt{A_2^2 + B_2^2} \sin(2\,Pt + \phi_2) + \ldots$$

where

$$\tan \phi_m = \frac{B_m}{A_m}$$

After having found the position of the armature of the sine dynamo for coincidence of zero points, its current is thrown in without taking care to adjust the phase. In general the dynamos will be out of step by an angle θ. Therefore

$$D_m = \frac{KK_s}{2\pi} \int_{-\pi}^{+\pi} f(Pt) \sin (m\,Pt + \theta)\, d(Pt)$$

$$= \frac{KK_s}{2\pi} \left[\cos\theta \int_{-\pi}^{+\pi} f(Pt) \sin m\,Pt\, d(Pt) + \sin\theta \int_{-\pi}^{+\pi} f(Pt) \cos m\,Pt\, d(Pt) \right]$$

$$= \frac{KK_s}{2} \left[A_m \cos\theta + B_m \sin\theta \right]$$

$$= \frac{KK_s}{2} \sqrt{A^2_m + B^2_m} \sin(\theta + \psi)$$

$$\tan\psi_m = \frac{A_m}{B_m} \text{ a constant.}$$

D will have its maximum value when

$$\theta + \psi = 90°$$
$$\sin(\theta + \psi) = 1.$$

This shows us that if, after having thrown in the sine dynamo its phase is so adjusted that the deflection of the dynamometer is a maximum, then

$$\sqrt{A^2_m + B^2_m} = \frac{2D_m}{KK_s}$$

and furthermore

$$\tan\phi_m = \cot\psi_m$$
$$\phi_m = 90° - \psi_m$$
$$\phi_m = \theta_m.$$

θ is known from the displacement of the sine armature from its zero position. As θ has proved to be such an important quantity, it would be better to determine it by finding the point where D becomes zero and reckoning back 90°, which would enable us to use a very sensitive dynamometer for this part of the work. In general all the waves of an alternator throughout a revolution are not identical, so the analysis would be commenced with terms of the same period as that of the revolution of the armature. It would seem that the above method could be applied to uses other than that stated if the mechanical

difficulties can be overcome; for if it is desired to analyze a given curve, we might, by means of a suitable cam, so guide a contact along a slide resistance through which a steady current is flowing that the current in a derived circuit would have the form of the given curve; this current could be analyzed as before.

The method assumes that a truly sinusoidal current is at our disposal. In this respect it may be said that there have been designed and constructed at the Rogers Laboratory small dynamos for use in other work, the E. M. F's. of which follow the sinusoidal law very closely; the current obtained from them could be rendered sinusoidal by the introduction of suitable condensers and inductances.

ROGERS LABORATORY OF PHYSICS.
June, 1893.

NOTES ON NORMAL INTESTINAL BACILLI OF THE HORSE AND OF CERTAIN OTHER DOMESTICATED ANIMALS.

By HARRISON G. DYAR, S.B., and SIMEON C. KEITH, Jr., S.B.

Received July 29, 1893.

It has been occasionally stated that the bacillus normally found in the intestines of man, *B. coli communis E.*, probably occurs as well in the lower animals. On the other hand, this organism has been supposed to be peculiar to man, and it has been suggested that its presence in water would serve as an indication of the pollution of that water by human excreta.

We are unaware that any positive investigations have been undertaken hitherto to determine this point. We have, therefore, studied the intestinal bacteria of several domesticated animals, namely, the horse, goat, rabbit, cat, dog, hog, and cow. In the goat and rabbit no normal bacillus was present. *B. coli communis* was not found, except occasionally, and then only in very small numbers. In the fæces of the rabbit very few bacteria of any kind were found, and occasionally the fæces were found to be sterile.

In the cat, dog, hog, and cow, *B. coli communis* was found in abundance. It usually occurs in nearly pure cultures, and is always found in greater numbers than any other bacillus, appearing to be as normal to these animals as it is to man. In the hog a large number of different bacilli occurred; but they were different in different individuals and were far outnumbered by *B. coli communis.*

The species were differentiated by their growth on plain agar, Wurtz agar, glycerin agar, gelatin, bouillon, nitrate solution, milk and potato, and by the formation or non-formation of gas in the Smith fermentation tube. On all these media the characters of the bacilli derived from the animals experimented upon corresponded with those of *B. coli communis* derived from human fæces.

In the horse we found a different state of affairs. In every instance there occurred, sometimes in pure cultures, a peculiar bacillus which we do not find described. It appears to be the normal intestinal bacillus of this animal, bearing the same relation to it that *B. coli communis* does to man and some other animals. We propose to characterize it under the following name:

BACILLUS EQUI INTESTINALIS (*new species*).

A non-motile, short bacillus with rounded ends. Dimensions 1 μ wide and from 1 μ to 2 μ long when grown on agar. In a preparation stained with carbol-fuchsin, the dimensions appear to be 0.8 μ × 0.9 μ. The bacilli are rather unequal in size and shape, and produce no color on any of the media. The species does not grow at 20°C., so no growth was obtained on gelatin. A culture on agar kept at 20°C. for a week showed no signs of growth; but on exposure to a temperature of 37½°C. for twelve hours the characteristic growth appeared. In agar tubes a thin, transparent, and almost invisible growth is produced, usually in small round spots about 1 mm. in diameter, more or less isolated. The culture does not spread over the surface. In an agar stick culture a growth appears along the length of the stab, becoming at length somewhat feathery. Wurtz agar is slowly reddened. This is shown especially well in a stick culture, where sections of the agar show a red area around the puncture. No gas is produced in the Smith tube, but turbidity throughout. Nitrate is not readily reduced, but after a week or longer the test gives a faint color. Milk is coagulated in two days. All cultures grown at 37½°C. *Occurrence:* Normally in the fresh fæces of the horse, often in the absence of other bacilli.

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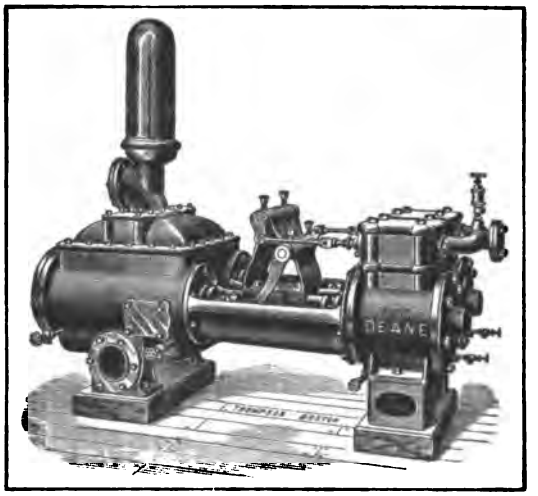

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Vol. VI. DECEMBER, 1893. No. 4.

TECHNOLOGY QUARTERLY

AND PROCEEDINGS OF THE SOCIETY OF ARTS

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PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. VI. DECEMBER, 1893. No. 4.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-SECOND YEAR, 1893-94.

THURSDAY, November 9, 1893.

THE 450th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Professor W. T. Sedgwick in the chair.

The records of the previous meeting were read and approved. Messrs. Herbert H. Barnes, James L. McQuarrie, and George S. Moynahan, of Boston, Charles M. March, of Portland, and J. Foster White, of Brookline, were duly elected Associate Members of the Society.

The following paper was read by title:

"Origin of Parallel and Intersecting Joints," by Prof. W. O. Crosby.

The Chairman then introduced Mr. George W. Fuller, Biologist in charge Lawrence Experiment Station, who read a paper on "The Removal of Pathogenic Bacteria from Drinking Water by Sand Filtration." The paper is printed in full in the present number of the *Quarterly*. It was followed by discussion on the part of the Chairman and others, and the meeting then adjourned.

THURSDAY, November 23, 1893.

The 451st meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Dr. D. R. Dewey in the chair.

The records of the previous meeting were read and approved. Messrs. Charles H. Alden, Jr., Charles C. Blake, Robert D. Evans, Joseph H. Goodspeed, W. B. Hardy, George H. Hood, G. Russell Lincoln, John A. Pray, and Walter I. Towne, all of Boston, were duly elected Associate Members of the Society.

The following papers were read by title:

"Determination of the Electrolytic Dissociation of Salts in Solubility Experiments," by A. A. Noyes, Ph.D.

"On Wurtz's Method for the Differentiation of Bacillus Typhi Abdominalis from Bacillus Coli Communis, and its Application to the Examination of Contaminated Drinking Water," by Albert P. Mathews, S.B.

The Chairman then introduced Hon. Frank P. Bennett, of Everett, who read a paper on "The Endowment Craze in Massachusetts." After a long discussion of the subject and of related topics, the Chairman extended the thanks of the Society to Mr. Bennett, and declared the meeting adjourned.

THURSDAY, December 14, 1893.

The 452d meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. Messrs. Francis Harrington, William H. Goodwin, Jr., Alfred H. Sawyer, E. N. Foss, and Henry P. Curtis, all of Boston, were duly elected Associate Members of the Society.

The following papers were read by title:

"Note on Normal Intestinal Bacilli of the Horse and of Certain Other Domesticated Animals," by Harrison G. Dyar and Simeon C. Keith, Jr.

"Preliminary Note on a Method for the Harmonic Analysis of Alternating Currents," by Frank A. Laws, S.B.

The President then introduced Mr. Howard A. Carson, Chief Engineer of the Metropolitan Sewerage Commission, who read a paper on "The Metropolitan Sewerage System of Massachusetts." The paper was very fully illustrated with the lantern, and is printed in the present number of the *Quarterly*. At its close the President extended the thanks of the Society to Mr. Carson, and declared the meeting adjourned.

CLEMENT W. ANDREWS, *Secretary.*

SOME RECENT PHOTOGRAPHIC INVESTIGATIONS OF THE SUN.

By GEORGE E. HALE, S.B.

Read October 25, 1893.

PHOTOGRAPHY has long occupied an important position among the methods of solar research. To it we owe the valuable record of the spotted condition of the sun's surface preserved at Greenwich; accurate representations of the corona obtained at total eclipses since 1860; the beautiful maps of the solar spectrum of Rowland and Higgs; and, to name no others, a score of such additions to our knowledge. In very recent times it has been applied to the study of the spectra and forms of the chromosphere, prominences, spots, and faculæ. It is the purpose of the present paper to describe briefly some of the methods and results of these more recent investigations.

THE ULTRA-VIOLET SPECTRUM OF THE CHROMOSPHERE AND PROMINENCES.

The advantages offered by photography for exploring the invisible region of the ultra-violet were early recognized, and spectroscopists were not slow to avail themselves of this means of recording the more refrangible portions of solar and metallic spectra. It was not until the spring of 1891, however, that the first photograph of the ultra-violet prominence spectrum taken apart from a total eclipse was obtained at the Kenwood Observatory. In these early photographs the principal thing that strikes the attention is the great intensity of the bright H and K lines. It was found that these lines were always present in prominences, where they were not only much brighter than the hydrogen lines, but seemed to attain even greater elevations above the limb. Careful wave-length determinations showed the bright H and K lines of the prominences to agree in position with the two strong lines of the calcium spectrum in this region, and there can thus be

little doubt that the calcium plays a most important part in solar phenomena. By comparing in intensity and length the H line of calcium and the slightly less refrangible line of hydrogen in a photograph taken with radial slit, it will be seen that calcium sometimes ascends to even greater elevations than hydrogen. For this reason Professor Young has doubted whether the heavy molecules of calcium may not be converted into some light form by the intense heat of the sun.

The distorted forms of the H and K lines, indicating motion in the line of sight, are photographed with great ease, and accurate determinations of velocity can be made by measuring the negatives. In such work the sensitive plate has great advantages over the eye, for the changes in form of the distorted lines are frequently too rapid to admit of accurate visual measurement.

The first photographs of the chromosphere and prominence spectrum were taken with a telescope having a 12-inch *visual* objective, and consequently but a small portion of the more refrangible region of the spectrum was in focus on a single plate. In addition to the H and K lines and the hydrogen line near H, the two hydrogen lines α and β[1] of the stellar series were obtained. Subsequently a 12-inch *photographic* objective made it possible to obtain photographs in which seventy-four ultra-violet lines are shown. Among them are the entire series of hydrogen lines occurring as dark lines in the ultra-violet spectra of the white stars. In addition to the magnesium triplet at λ 3830 and a number of iron lines, there are many lines as yet unidentified.

Thanks to the aid of photography, the ultra-violet spectrum of the chromosphere and prominences is now as well known as the visible spectrum.

CHROMOSPHERE AND PROMINENCE FORMS.

Prior to the work at the Kenwood Observatory but one photograph of the form of a prominence had been taken without a total eclipse. In 1870 Professor Young used the H line for this purpose, the image of a prominence through a widely open slit being received on a wet collodion plate. The result was so unsatisfactory that the experiment was not repeated.

[1] In the nomenclature for the hydrogen series proposed by Vogel and Huggins, the lines referred to are designated ζ and η.

The discovery of the extreme brightness of the H and K lines in prominences, together with the breadth of the dark bands in which they lie, seemed to offer new encouragement for work in this direction, and fairly good photographs of prominence forms were made at the Kenwood Observatory through an open slit by the aid of these lines. The completion of the spectroheliograph in January, 1892, made it possible to secure better results.

The spectroheliograph is an instrument by means of which any object may be photographed in monochromatic light. The construction of the instrument varies somewhat for different classes of work. A form which has proved very satisfactory for general solar investigations consists of a large, grating spectroscope provided with two movable slips — one at the focus of the collimator, the other at the focus of the observing telescope. These are connected by levers, and operated by hydraulic pressure in such a manner that when the K line of the fourth order spectrum of the grating is made to fall upon the second slit it remains there, no matter how the slits are moved. The photographic plate is placed with the sensitive surface almost in contact with the jaws of the second slit. In photographing the chromosphere and prominences it is only necessary to exclude the light of the sun's disk by a suitable diaphragm, and allow the first slit to move slowly across the solar image. The photograph is built up from a series of successive images of the bright K line.

The advantages thus afforded over the visual method of recording the varying forms of the chromosphere and prominences are numerous. Errors on the part of the observer are done away with, time is saved, and portions of the prominences too faint to be seen by the eye are obtained on the photograph. Such a picture can be made in two minutes, though better results are secured by limiting the width of the slits to about $\frac{1}{200}$ of an inch and giving an exposure of nearly twenty minutes. The most skilled observers require over an hour to sketch the sun's circumference through the C line, so the gain in time is no less evident than the gain in accuracy. Photographs of short-lived eruptions can be made at the rate of several per minute, and the substitution of a train of prisms for the grating would render possible much shorter exposures.

The series of photographs shown[1] illustrate the manner in which

[1] The paper was illustrated with the stereopticon.

prominences sometimes develop. It will be noticed that a streamer shot out nearly horizontally from a brilliant center of action far above the sun's limb, and finally descended to meet the chromo-sphere. The changes here recorded occupied thirty-four minutes.

Photographs of prominence forms in the F line show certain points of difference when compared with simultaneous photographs in the K line, principally in the greater extent of the region occupied by calcium.

WHITE PROMINENCES.

The question of the "white prominences" has naturally received attention. It will be remembered that at the eclipse of 1886 a prominence 150,000 miles high was shown in the photographs, and observed during totality. Neither before nor after totality could Professor Tacchini detect any trace of it with the spectroscope. A photograph of the spectrum taken by Prof. W. H. Pickering showed H and K with a bright, continuous spectrum, but none of the hydrogen lines seemed to be present. Such prominences are therefore invisible in visual observations through the C line, but they should be obtained in photographs taken with the spectroheliograph through the K line. As yet no such prominences have been detected on the Kenwood Observatory plates, though in most cases complete visual observations for comparison have been lacking. In the large number of photographs taken of prominence spectra, H and K have invariably been accompanied by the more refrangible hydrogen lines. A continuous spectrum has been photographed in the case of a few violent eruptions.

FACULÆ AND SPOTS.

The discovery at the Kenwood Observatory in December, 1891, that the H and K lines are invariably reversed in faculæ, opened a new field of application for the spectroheliograph. It is evident that the same procedure followed in the case of the prominences on the sun's limb will serve equally well for prominences or faculæ on the disk, provided only that they give sufficiently bright reversals of the calcium lines. In fact, the first photographs taken with the slit traversing the sun's disk showed the faculæ, not only near the limb — where alone they are visible in ordinary photographs or visual observations, — but also in the very brightest parts of the image. A

comparison of two photographs will illustrate this difference. One is a copy of a photograph of the sun taken at the focus of a photographic objective in the ordinary manner. The faculæ are shown only near the limb. It is from such photographs, which agree well with visual observations, that the accepted opinion of the condition of the sun's surface has been derived. From this point of view the spots are evidently the surface phenomena of first importance. But a glance at the next photograph, taken with the spectroheliograph, reveals an entirely different state of things. The faculæ are as clearly shown in the center of the image as at the limb; and the study of their relations with spots, their position and changing forms, once so difficult, now becomes easy. Since February, 1892, when the spectroheliograph was first successfully employed to photograph prominences and faculæ, over 2,600 negatives have been obtained with it. A record of the condition of the solar surface, as complete as the weather would allow, has thus been secured to supplement the series of spot photographs made in the ordinary way at Greenwich.

If the two pictures are closely compared it is seen that there are marked differences in the appearance of the spots. The faculæ almost invariably encroach on spot penumbræ, and small spots are frequently covered by masses of calcium faculæ. The great area covered by faculæ is surprising to any one accustomed to think of the solar surface as dotted with spots. M. Tacchini's visual observations of faculæ give the average total area as about equal to the average total area of spots. The present photographs show that the eye really perceives only a small fraction of the actual area covered by faculæ. It has also been found that small faculæ, less brilliant than those just referred to, mottle the entire surface of the sun, and extend from pole to pole. They are apparently parts of a continuous network which completely envelops the sun. This is somewhat delicate, and can only be well seen in the original negatives.

The forms assumed by faculæ are very peculiar, and in many cases decidedly suggestive. Sometimes the groups are very extended in a direction parallel to the equator, and the almost unbroken belts thus formed suggest planetary analogies, and perhaps refer to a past or future stage in solar evolution. Sometimes the groups are irregularly scattered over the disk. The changes of form are gradual, and ordinarily the configuration of a group is not materially altered in an interval of several hours. Examination of the plates has revealed a

distinct tendency in the faculæ toward curved forms. On 49 negatives taken on different dates, 245 cases of smooth curves in the forms of faculæ were noticed on casual inspection, and in 97 cases the curved faculæ terminated in bright circular heads, some of them containing minute spots. Spiral forms were found to be not uncommon; but the form which appears in the vast majority of cases is like that of a figure 3, usually with two, sometimes with three or more, loops. As everything points to the conclusion that the eruptive prominences spring from faculæ, the helical forms frequently observed or photographed in prominences may be associated with curved faculæ.

ERUPTIONS ON THE SUN'S DISK.

Perhaps the most interesting of the phenomena brought to light by the spectroheliograph are eruptions on the sun's disk. The celebrated observation by Carrington and Hodgson, in 1859, of two brilliant objects moving across a spot has never been exactly duplicated, but by the aid of the spectroheliograph eruptions invisible to the eye are sometimes recorded. A photograph of the sun, showing faculæ, spots, and prominences, was taken on July 15, 1892, at about 11.8 A.M. (Chicago M.T.), which showed nothing unusual in a spot in the southern hemisphere, except that the facula running between the northern and southern umbræ of the spot was brighter than usual. The next photograph, taken at about 11.20, showed a very different state of affairs. Extending between the umbræ, in a direction slightly inclined to the sun's equator, was a perfectly straight and exceedingly brilliant object, which expanded slightly at its eastern extremity, and turned sharply toward the north, terminating abruptly in a brilliant ball just east of the center of the northern umbra. The sudden formation of this remarkable object did not seem to affect the general group of faculæ surrounding the spot, for they remained of practically the same form as at first. As the plates were not developed immediately, nothing was known of the disturbance, and the next photograph was not taken until 11.47. Meanwhile an entire transformation had taken place in the luminous phenomenon, and so completely were the umbræ covered by the brilliant outbursts that they were no longer visible in the photograph. The straight tongue running between the umbræ in the first photograph had developed into an S-shaped form, similar in appearance to a facula shown in our photographs of

the great February, 1892, sun spot when on the eastern limb. Brilliant forms had also appeared to the northwest of the northern umbra, and the disturbance extended over an area of about four billion square miles.

Unfortunately no more exposures were made until 1.21, when eleven photographs of the spectrum of various parts of the spot region showed nothing out of the ordinary. A photograph of the sun exposed at 1.41 and another at 1.50 show the forms of the great region of faculæ surrounding the spot to be the same as they were before the disturbance, which had now completely disappeared.

Similar, though somewhat less extensive, eruptions have been photographed with the spectroheliograph on June 20, 1892, and January 26, August 3, 6, and 10, and September 14 of the present year. They have all occurred in the vicinity of spots, and have been of brief duration. In no case has the disturbance commenced in the umbra of a spot, nor have the surrounding spots and faculæ been materially altered in form by the outburst. It would then seem that we were dealing with true eruptions seen in projection. The forms are frequently more or less spiral, and recall the curved forms of faculæ already referred to. It is not impossible that the phenomena are those following the fall of meteoric matter into the sun; but if this were the case the chances would be against the invariable occurrence of the disturbance in a spot group, unless the group were supposed to exercise some attractive force on the meteoric mass. On the whole, the eruptive theory certainly seems preferable.

SOLAR DISTURBANCES AND TERRESTRIAL MAGNETISM.

The question as to the manner in which solar disturbances and terrestrial magnetic storms are related has long been under discussion, and its present condition is one of great uncertainty. The apparent existence of a twenty-seven-day period in the recurrence of magnetic perturbations is considered by some to indicate that disturbances in certain regions of the sun's disk — at the eastern limb or the central meridian, for instance — are alone capable of affecting the magnetic needle. To prove this it has been shown that the maxima of curves of magnetic intensity generally coincide with the appearance at the sun's central meridian of a spot or facula. Others have been no less successful in finding a spot or facula at the sun's eastern limb when-

ever an aurora is seen. To test whether these coincidences might not be due to chance, photographs of faculæ taken on one hundred and forty-two days in 1892 at the Kenwood Observatory were examined. It was found that for 1892 the probability that at any time one or more groups of faculæ would be on a given meridian of the sun was 0.93. Under such conditions it would be almost impossible for an aurora or magnetic storm to occur without the simultaneous existence of faculæ at either the central meridian or the eastern limb, and such coincidences must therefore be regarded as of doubtful importance.

As for the eruptions photographed on the solar disk, that of July 15, 1892, was simultaneous with "a slight trembling in the horizontal force magnet, which was the prelude to the violent storm which set in and lasted over the 16th and until midnight of the 17th." A similar though less important eruption shown on a spectroheliogram taken June 20, 1892, was not accompanied by a disturbance of the magnets, but a series of small oscillations commenced one day later, and lasted until June 26. Eruptions on January 26 and August 3 and 10, 1893, were without corresponding maxima on the magnetic curves. On August 6, 1893, there was a slight magnetic disturbance simultaneous with a small eruption.

THE GREAT SUN SPOT OF AUGUST, 1893.

The great sun spot which was a conspicuous object to the naked eye during the first two weeks of August last was remarkable in many ways, but especially for the fact that two eruptions were recorded in it by the spectroheliograph during its passage across the disk. On August 3, at 10.1 A.M., the group was an inconspicuous object near the sun's eastern limb. There are indications in the photograph of a disturbance in the faculæ south of the spot, and a plate exposed nine minutes later shows a brilliant eruption of strange form. From this time forth the spot group increased rapidly in size. It was preceded by a great area of faculæ, but not inclosed in one, as was the great sun spot of February, 1892. A photograph taken on August 5 shows what a great change the group had undergone in the interval of two days. This is especially noticeable in the following spot, which, on August 3, was small and covered by faculæ. On August 7 both spots and faculæ were still further developed, a bright bridge of faculæ had been thrown across one of the spots, and a small spot had broken out

in the faculæ preceding the group. The changes indicated on the photographs of the following day were confined principally to the faculæ surrounding the preceding member of the group. The bright bridge of faculæ had disappeared, and with it a mass of faculæ to the east, which before had covered two small spots. On August 9 all of the spots had become more regular in form, the faculæ were considerably changed in appearance, and once more nearly covered some of the smaller spots. One day later the two smaller groups into which the following spot had already divided were nearly equal in size. This segmentation seemed to be due to the formation on August 8 of a bright bridge of faculæ, which steadily increased in size. On August 12, when the group was near the western limb, the following spot was still further divided.

Such, in brief outline, is the history given us by monochromatic photography of the passage of a large spot group across the visible hemisphere of the sun. The numerous negatives secured each day will furnish material for a detailed study of the faculæ and their changes, and may lead us a step nearer to a true understanding of their origin.

NATURE OF THE FACULÆ.

Certain of the solar theories advocated at the present time explain the faculæ as phenomena secondary to the spots. Faye supposes the chromospheric matter to be drawn into the cyclone of the spot and released at the lower end of the funnel, where it receives new supplies of heat from the interior of the sun and forces its way to the surface, thus forming a ring of faculæ surrounding the spot. During the celebrated discussion of this and other solar theories recorded in the *Comptes rendus* of the French Academy, M. Tacchini naturally objected that this explanation did not suffice for faculæ not in the vicinity of spots. M. Faye replied that the entire body of the sun is covered with minute whirlpools, which maintain the supply of heat for radiation by causing a constant circulation of the chromospheric matter. When these pores are closely crowded together they produce faculæ, just as the spot does in the explanation already given.

The inadequacy of this explanation can hardly be doubted after an examination of even a limited number of spectroheliograms. While not yet made certain by a prolonged study of the plates, it seems more than probable that faculæ, and not spots, are the first evidences of

solar disturbances. But whether this be true or not, numerous cases might be cited in which groups of faculæ containing no spots, or at most small and insignificant ones, were far larger and more brilliant than faculous areas accompanying spots of the largest size. The photographs which illustrate the partial history of the great spot group of August last exhibited an excellent case of this kind. Moreover, no evidence has been advanced to substantiate M. Faye's hypothetical crowding of pores in regions of faculæ.

As to the nature, if not the cause, of faculæ there can be little difference of opinion. The spectroheliograms confirm what has long been known, that faculæ are elevations above the general level of the photosphere. Besides glowing with the continuous spectrum of the cloudlike photospheric matter, they exhibit the H and K radiations of calcium with marked intensity. The Kenwood Observatory photographs invariably show these bright lines divided with a dark line of absorption. Indeed, in some instances, there is a continuation of the doubly reversed line across a portion of the solar disk and into the chromosphere. Hence the faculæ, and sometimes large areas of the photosphere, show certain evidence of the presence of unbroken regions of extremely hot calcium vapor, capped with cooler vapor of the same kind. The prominences are not ordinarily clothed in such shells of cool calcium vapor, at least not in sufficient thickness to cause a second reversal of the lines. But occasionally a violent eruption brings out the double reversals in the lower parts of the resulting prominence, and the chromosphere at the limb invariably gives a double reversal like that of a facula. In sun spots the double reversal in the surrounding faculæ usually narrows down into a single bright line over the umbra. This is probably due to the chromosphere overlying the cooler region of the spot. It may also be pointed out that the bright H and K lines over spots are almost invariably of the type shown in this photograph. In the numerous photographs of this kind made at the Kenwood Observatory there are in a few instances a slight widening of the bright lines. In most cases the lines are undistorted and of normal width. Such immobility is hardly compatible with any theory requiring rapid downrushes or uprushes in spots.

Singularly enough, hot hydrogen does not seem to be a common constituent of faculæ. The F line is very rarely reversed in them, so that ordinarily no traces of the faculæ are shown in photographs of the sun made by setting the F line, instead of the K line, on the second slit of the spectroheliograph.

To inquire into the relations existing between prominences and spots and faculæ would prolong this paper beyond reasonable limits, and it will suffice to say that the spectroheliograph affords excellent material for such an investigation. A photograph from a single original negative showing all of the solar phenomena within our reach can be made in a very simple way by means of a double exposure.

The photographic record of prominences and faculæ hitherto obtained only at the Kenwood Observatory will shortly be supplemented by similar work in India. Prof. K. D. Nægamvala, director of the observatory at Poona, has decided to obtain a spectroheliograph, with which the sun will be photographed as frequently as possible. As the observatory is separated from Chicago by about 160 degrees of longitude, and is favored by clear skies during the greater part of the year, the solar record should henceforth suffer few serious interruptions.

The study of solar physics will never be altogether satisfactory, however, until photographs of the sun show not only faculæ and spots, and the chromosphere and prominences, but the corona as well. Still hidden in the glare of atmospheric light, the corona is revealed only on the occasion of a total eclipse, and knowledge gathered in such brief intervals of time is necessarily meager. The photograph on the screen represents an instrument on the principle of the spectroheliograph used on Pike's Peak a few months ago in an attempt to photograph the corona without an eclipse. Clouds of smoke from extensive fires in the forests surrounding the peak made a satisfactory test of the instrument impossible, and no images of the corona were obtained. It is hoped that the experiment may soon be repeated, though it must be admitted there is small chance of success. But in Italy and France, in England and America, this difficult problem is under investigation, and its solution may not be far distant.

THE REMOVAL OF PATHOGENIC BACTERIA FROM DRINKING WATER BY SAND FILTRATION.

By GEORGE W. FULLER, S.B., Biologist in Charge Lawrence Experiment Station.

Read November 9, 1893.

That drinking water is a carrier of some diseases there can be no doubt. Numerous laboratory experiments by many investigators indicate that the bacteria generally considered to be the specific organisms of typhoid fever, Asiatic cholera, and other diseases, live in ordinary drinking water for many days. The results of long-continued investigations at the Lawrence Experiment Station show that the typhoid bacillus continues to live in the water of the Merrimack River at Lawrence in greatly diminished numbers for a period of twenty-four days. Other investigators, using different water and different conditions, estimate the length of life of this germ at from three to eighty days. The duration of life of the cholera spirillum in various waters has been observed to be from two days to seven months.

Modern hygiene demands that drinking water shall be free from pathogenic bacteria, and the means by which such water can be obtained are worthy of our most careful consideration.

In some localities satisfactory supplies of pure water can be had from driven wells and from surface water taken from watersheds which are free from human habitation. It is very rare, however, that great cities with their large suburban population can obtain a sufficient quantity of perfectly safe drinking water from either of these sources. Many water supplies drawn from polluted sources have been introduced in America in recent years with the belief that the impurities were removed from the water on its passage to the consumers. It is true that a certain degree of bacterial purification is effected by dilution, by storage in a reservoir holding one or two weeks' supply, and

by passage under pressure through miles of iron pipe. But the experience of numerous cities, involving the loss of hundreds of human lives, shows conclusively that all of these conditions taken together are insufficient to render an infected water safe at all times for drinking purposes.

At the present time many cities and towns — and the number is constantly increasing — are obliged to face the problem, How can the pathogenic bacteria be best removed from a polluted water? From the results of long continued scientific investigations, together with the experience of certain European cities, it is fully believed that the requirements of modern sanitary science are satisfactorily fulfilled by properly conducted sand filtration.

Sand filtration was first introduced near London, by James Simpson, in 1839. It is the practice in Europe to pass the water through fields of thoroughly underdrained sand from three to five feet in depth. The surface of the sand is kept continually covered with water. The sediment in the unfiltered water is deposited on and very near the surface of the sand. This gradually increases the resistance to the passage of the water through the sand until a point is reached when the quantity of water yielded by the filter is so small that it is necessary to scrape the filter, that is, to remove the upper layer of clogged sand.

During the past forty years many filter plants have been constructed in Europe, and numerous improvements in the filtration of water have been made particularly during the past decade. This is largely due to the aid of bacteriology, which enables us to determine the actual efficiency of filters with regard to the removal of bacteria. The operation of some European filters is quite satisfactory, as is shown both by the low death-rates from those diseases conveyed by drinking water and by the results of numerous bacteriological investigations.

The water from the river Thames — the source of a part of the London water supply — was examined bacterially for several years by Prof. Percy Frankland before and after filtration. The average results for the years 1886, 1887, and 1888 showed an average removal of 97.6 per cent. of the bacteria in the unfiltered water. The average typhoid fever death-rate in London during these years was very low, namely, 1.6 per 10,000 inhabitants.

The operation of the Berlin filters has also been watched very

closely, particularly the works at the Stralauer Thor, which were under the direction of Piefke, the eminent engineer, with whom it was my privilege to study for a short time. Through the investigations of Piefke and the bacteriologists of the Hygienic Institute at Berlin, our knowledge upon the removal of bacteria from water by sand filtration has been much extended.

In 1887 the State Board of Health of Massachusetts established an Experiment Station at Lawrence. The object of this was to study the laws of filtration. The Experiment Station was designed by Mr. Hiram F. Mills, A.M., C.E., the distinguished engineer, who has directed the investigations. During the earlier history of the work attention was devoted chiefly to sewage filtration. The fact that typhoid fever has been epidemic from time to time in certain Massachusetts cities gave an increased impetus to the study of water filtration during the past two years.

In the fall of 1887 a tank 6 feet deep and 17 feet 4 inches in diameter was filled with mixed coarse and fine sand and a layer of fine loam 8 inches thick, the top of which was 6 inches below the surface. The total depth of the filtering material was 5 feet. Beginning in January, 1888, water from the Merrimack River, which had passed through the reservoir and service pipes of the Lawrence Water Works, was applied to this filter sixteen hours a day. The filter was allowed to drain during the rest of the time and the pores of the sand fill with air. Such a filter is known technically as an intermittent filter, in distinction from the continuous filters the surfaces of which are constantly covered with water.

The number of bacteria in the effluent of this filter was very low, usually below ten per cubic centimeter, and at times it was sterile. In May, 1891, elaborate preparations were made to settle with certainty whether any of the bacteria found in the effluent came down through the filtering material with the applied water, or whether they had their origin in the underdrains according to the theory of Bertschinger and other Europeans. The greatest care was taken to prevent contamination of the effluent by air and dust. The average results of 186 bacterial determinations indicated that from May to October, 1891, the applied water contained 175 and the effluent 4.7 bacteria per cubic centimeter. This was a removal of 97.3 per cent. of the bacteria in the unfiltered water.

To obtain more definite knowledge upon the subject, river water

taken directly from the canal was applied to the filter, commencing November 13, 1891. Repeated determinations of the bacteria in the river water and in the effluent were made daily on the same nutrient gelatine, grown for the same length of time and at the same temperature. Many duplicate determinations were made, and it was found that no further development occurred when the plates were allowed to stand six and even eight days. Quantitative determinations of the species of bacteria in the filtered and unfiltered water were made at frequent intervals. One of the most striking results of this work was that *B. coli communis*, the leading species in human fæces, was found during November and December, 1891, to form 39 per cent. of the bacteria in the water of the Merrimack River at Lawrence. This species of bacteria, however, was not found in the water after its passage through the filter.

The results of the investigation upon the removal of bacteria by this filter may be summarized as follows:

1. The application of river water instead of city water, which increased the number of applied bacteria more than tenfold, was followed by no increase whatever in the total number of bacteria in the effluent of this filter.

2. Of the 102 bacterial determinations of the effluent from November 14 to December 31, inclusive, 58 indicated that the filtered water was sterile.

3. No relation could be found between the rate of flow of the water through the filter and the number of bacteria in the effluent.

4. As a result of numerous species determinations it was found that three of the most prominent kinds of bacteria in the river water were not present in the filtered water. Among these species was *B. coli communis*, which is the leading species in fæces, and which resembles in many ways the bacillus of typhoid fever.

5. The presence of the very small numbers of bacteria in the effluent was satisfactorily explained by their specific similarity to those present in the air, the outlet pipes, and the underdrains.

From this evidence it was concluded that with these filtering materials and under these conditions all the bacteria of the Merrimack River water may be removed by filtration.

This filter was continued during the following year, and the degree of bacterial removal remained most satisfactory. The maximum

amount of water purified by this filter has not exceeded 250,000 gallons per acre daily. The adoption by cities and towns of water filtration through such materials would be very costly; and a large portion of our attention has been devoted to the study of filtering materials coarse enough to filter a municipal water supply economically, while removing the pathogenic bacteria.

Fourteen new experimental water filters were constructed during 1892. The construction and operation of the filters were such as to throw as much light as possible upon the laws of filtration. Since the removal of bacteria is one of the most important points in the filtration of water, the investigations were arranged so as to allow direct comparison of the power of removal of bacteria from water under different rates of filtration, with sands of different degrees of coarseness, with different depths of the same sand, with the presence of loam layers, and with intermittent and continuous filtration.

The actual efficiency of the filters was tested by the application of typhoid fever germs, as well as other prominent species, and observations upon their passage through the filters. The pure cultures of the microörganisms were grown in dilute bouillon solutions, and 25 or 50 cubic centimeters of these solutions containing millions of germs were applied usually in a gallon of water to the filters. The course of the dose through the filters was followed in many cases by adding a small quantity of common salt with the dose and examining the effluent for chlorine. Bacterial examinations of the effluent were made at frequent intervals for several days.

It is obviously impossible to discuss here in detail the results which are presented in the several reports of the Board, and it is the purpose in the present paper to outline the methods of investigation and summarize the results.

During the first five months of 1892, fifty-five experiments upon the passage through the filters of pure cultures of bacteria in single doses were made with results which are summarized as follows:

TABLE NO. I.

Filter No.	Number of experiments.				Number of bacterial determinations.	Number of bacteria per cc. applied.	Per cent. removed.
	Typhoid.	B. prodigiosus.	B. coli communis.	Total.			
18 A	3	1	0	4	131	142,600	99.56
35	3	0	0	3	41	3,630	100
36	3	0	0	3	46	9,270	100
33 A	0	1	1	2	25	275,000	100
34 A	0	1	1	2	25	227,000	100
35 A	4	2	2	8	146	77,630	98.02
36 A	3	2	2	7	136	145,800	99.33
37	1	4	2	7	105	121,000	99.999
38	1	2	2	5	73	44,500	99.80
39	2	3	2	7	93	42,800	99.09
40	2	3	2	7	93	57,000	98.43
Averages and totals	22	19	14	55	914	104,200	99.48

These experiments were very severe tests upon the efficiency of the filters in removing bacteria, because the number applied was probably greater than would occur in practice, and, furthermore, the organic matter introduced with the bacteria served them as a food material. The experiments made during the latter portion of the year are much fairer, because the bacteria were applied in small and long-continued doses at frequent intervals and less organic matter was put into the filters. Pure cultures of the different species of bacteria were obtained by inoculation and growth for four days at 20°C. in solutions of one tenth per cent. peptone and two tenths per cent. glucose in city water. It was found that this solution contained on an average about 20,000,000 bacteria per cubic centimeter. This solution was applied to the filters, in the proportion of one part to three thousand parts of water, at intervals of one or two hours, according to the rate of filtration. Every cubic centimeter of water which went into the filters during the experiments contained, as a rule, about 6,000 bacteria of the pure culture in addition to those water bacteria ordinarily present. It was determined, also, that the food material which was applied with

these germs did not increase the organic matter in the river water beyond the limits of variation which have been occasionally observed in it from month to month. Table No. II contains the average results of five analyses of the river water before and after adding to it this solution.

TABLE NO. II (parts per 100,000).

	Free ammonia.	Albuminoid ammonia.	Chlorine.	Nitrogen as		Oxygen consumed.
				Nitrates.	Nitrites.	
River water before inoculation .	.0056	.0172	0.19	.015	.0001	.52
River water after inoculation .	.0062	.0203	0.19	.015	.0001	.54

B. prodigiosus is the species of bacteria which has been used since September, 1892, almost without exception in these experiments. The reasons for using this species are: (1) the ready and accurate means for its differentiation; (2) its great similarity to *B. typhi abdominalis* in its mode of life in the river water — neither species multiplies, but both continue to live in greatly diminished numbers for fifteen to twenty days or more; (3) the fact that it has never been found native in this country, and we are therefore reasonably sure that the bacteria of this kind, when found in the filtered water, must have passed through the filter from the applied dose.

Beginning September 16, 1892, repeated doses of *B. prodigiosus* were applied at frequent intervals for ten hours daily to the several water filters. Throughout the experiment, from September 16 to December 31, four examinations were made daily of each of the effluents at times when the applied doses were passing through the outlet pipes.

In Table No. III is presented a summary of the average results of the daily application of *B. prodigiosus*, together with the depths of the filters and the average rates of filtration.

TABLE NO. III.

Filter No.	Depth of filter. (Feet.)	Rate of filtration (Gallons per acre daily).	Number of bacterial determinations.	Average number of B. prodigiosus per cc. applied.	Per cent. removed.
18 A	5	1,300,000	160	3,660	99.84
33 A	5	1,700,000	212	5,710	99.78
34 A	5	1,500,000	260	7,630	99.83
35 A	5	1,200,000	120	8,780	99.95
36 A	5	2,400,000	288	6,220	99.96
37	5	1,700,000	152	3,370	99.94
38	2	1,800,000	288	4,700	99.86
39	1	1,900,000	364	6,230	99.83
40	1	1,700,000	128	3,630	99.91
41	5	1,700,000	144	4,175	99.97
42	1	1,800,000	256	8,060	99.73
Average and totals .	....	1,700,000	2,372	5,700	99.87

Numerous determinations have been made of the ordinary water bacteria present in the unfiltered and filtered water. Beginning in June, 1892, all of the effluents have been examined once a day or oftener. As was indicated by the investigations upon Filter No. 8, the true degree of bacterial removal is somewhat obscured by the presence in the effluents of bacteria which do not appear to come down through the filter, but seem to have their origin in the underdrains, where they continue to live upon the very small amount of food present.

In Table No. IV is given a summary of the total averages of these results, including the bacterial examination of more than 5,000 representative samples of unfiltered and filtered water.

TABLE NO. IV.

Filter No.	Bacteria per cc. in river water.	Per cent. removed.
8	5,300	99.83
18 A	9,960	99.22
33 A	8,410	99.29
34 A	9,160	99.57
35 A	9,310	99.45
36 A	8,510	99.27
37	8,540	99.34
38	8,860	99.03
39	8,810	99.01
40	9,010	99.26
41	10,050	99.51
42	8,750	97.74
Averages	8,780	99.21

As has been stated already, the sediment in the unfiltered water is deposited upon and very near the surface of the sand. The surface sand in time becomes so clogged that it is necessary to scrape off $\frac{1}{8}$ to $\frac{1}{4}$ of an inch. When the experimental filters are to be scraped the water above the surface of the sand is removed with a siphon and the filter allowed to drain until the water lowers to about an inch below the surface of the sand. After scraping, the water is applied to the filters from the top. In Berlin it is believed that the efficiency of the filter depends upon the scum which is formed on the surface of the sand. In some places abroad it has been found that the effluent contains at times as many bacteria as the unfiltered water just after scraping. At Lawrence the efficiency of the filters in removing bacteria, under the existing conditions of operation, varies but very slightly during the period between scrapings. This is brought out very clearly by Table No. V, in which are given the average results of the bacterial examinations of the effluents for the three days before and the three days after scraping. They extend over the period from September 16 to November 27, when the several filters were running under nearly the same conditions before and after scraping. During

this time the number of ordinary water bacteria in the applied water averaged 13,600, and the number of *B. prodigiosus* for the ten hours of daily application, 6,400 per cubic centimeter.

TABLE NO. V.

Number of filter.	Water Bacteria.			B. Prodigiosus.		
	Number of scrapings.	Number during the three days before scraping.	Number during the three days after scraping.	Number of scrapings.	Number during the three days before scraping.	Number during the three days after scraping.
33 A	3	31	45	1	0	3.0
34 A	5	32	42	4	0.4	0.4
35 A	4	50	77	3	1.0	3.3
36 A	4	39	52	4	3.9	6.8
37	2	21	48	1	0	0.5
38	6	47	121	4	4.2	11.6
39	8	52	90	8	3.6	7.3
40	3	48	29	3	1.3	2.3
41	5	20	28	2	0.4	1.4
42	2	109	233	2	13.0	34.0
Totals and averages . . .	42	44	75	32	2.8	6.7
Average per cent. removed,	....	99.68	99.45	....	99.96	99.89

These results indicate that there are more bacteria in the effluent after scraping, but the increase forms only a small fraction of 1 per cent. of the applied bacteria. With coarser sands and higher rates of filtration this difference would probably become more marked.

The cause of the differences in the results at Lawrence and in Europe is not clear, because our comparative knowledge of the existing conditions is incomplete. The nature of the unfiltered water as well as the physical characteristics of the sand with which a filter is filled exert an influence upon the efficiency of filtration. Not only the absolute size but the relative sizes and the shape of the sand grains has an important bearing. Suppose we have two filters, each filled with sand grains of equal volume, but in one case in the form of cubes and in the other in the form of spheres; it is perfectly clear that very different results would follow. In Germany it is the practice, in some places at least, to wash out the finer particles before placing

the sand in the filter. This is not done at Lawrence. Samuelson, the chief engineer of the Hamburg Water Works, states in a recent paper that the best filtering sand is one in which all the grains are approximately one millimeter in diameter, and that the operation of the filter is much different if the sand is but little finer. The Lawrence results indicate that it is the finer particles of sand which determine its efficiency, for the reason that the finer grains fill up in part the spaces between the coarser grains.

It may be said, in passing, that an important feature of the work at Lawrence is the study of the physical properties of materials which govern their actions as filters. Great assistance has been obtained from relations already formulated. The effective size of a sand is considered as the maximum diameter of the finest 10 per cent. of the grains. The effective size of the most efficient experimental filters at Lawrence, that is, those which yield the most water between scrapings while removing substantially all of the bacteria, lies between 0.2 and 0.3 of a millimeter.

But, disregarding the true and entire explanation of the differences, the fact remains that the Lawrence filters are a greater safeguard than some European ones in the removal of pathogenic bacteria from drinking water, because their efficiency is more uniform.

It is to be stated in the case of the Lawrence filters, that it is the upper portion of the sand that largely accomplishes the bacterial purification. This is shown most clearly by Table No. VI, in which are given the numbers of bacteria per gram found in the sand at different depths of a continuous filter which had been in operation from May 2 to October 26, 1892. This filter was scraped on October 15, and was again clogged on October 26, the date of examination.

TABLE NO. VI.

Depth from surface (inches).	Bacteria per gram.
0 — ¼	1,100,000
¼	320,000
1	140,000
2	21,000
4	4,000
6	1,600

During the past year the city of Lawrence has constructed a large water filter, which has recently been put in operation. This filter, which was designed by Mr. Hiram F. Mills, is $2\frac{1}{2}$ acres in area and has a capacity of 5,000,000 gallons daily. Its construction is based upon the results obtained at the Lawrence Experiment Station. This filter, the only one of its kind in America, differs chiefly from those in Europe in that it is operated intermittently and the pores of the sand allowed to fill with air every day. This facilitates the oxidation processes and appears to have an advantage over continuous filters, because it removes more of the organic matter which accumulates at the surface of the sand.

With regard to its removal of bacteria from the river water, it may be stated that the efficiency compares very favorably with that of the experimental filters of similar construction. During the second week of operation the removal of bacteria from the river water was as high as 98 per cent.

In studying the death-rates of the large cities of the world which draw their drinking water from polluted sources, it is very clear that a great safeguard against certain diseases conveyed by drinking water is afforded by sand filtration. Thus London and Berlin, with originally polluted but filtered drinking water, had typhoid fever death-rates in 1891 of 1.3 and 1.0 per 10,000 inhabitants respectively; while, on the other hand, Chicago and Philadelphia, which use polluted and unfiltered water, had during the same year typhoid fever death-rates of 16.0 and 6.4 per 10,000 inhabitants respectively.

The most striking example of this point is the experience with cholera at Hamburg and Altona. This is probably familiar to all, but as it illustrates the point so well I shall outline it briefly.

Hamburg and Altona are on the river Elbe. Hamburg drew its water from the river above the city. Nominally the Hamburg water was purified by the use of settling basins. The system was overworked, however, and there was practically no settling at all. The city of Altona takes its water from the river below the outfall of the Hamburg and Altona sewers, but before using carefully filters it through sand. Wandsbeck, a neighboring city, receives its supply from an inland lake, and also employs sand filtration. During the cholera epidemic of 1892 Hamburg, with its unfiltered water, suffered severely; with a population of 622,530, it had 17,975 cases and 7,611 deaths from Asiatic cholera. Altona and Wandsbeck, on the other hand, supplied

with filtered water, suffered but little at this same time from cholera. Altona, with a population of 143,000, had 562 cases and 328 deaths; Wandsbeck, with a population of about 20,000, had 64 cases and 43 deaths. There is every reason to believe, moreover, that the cases which did occur in the two latter cities were imported from Hamburg, and were not due to local causes. German sanitarians also call attention to the fact that in a street which is a dividing line between Hamburg and Altona, the people on one side using Hamburg water fell victims to cholera, while their neighbors across the way using Altona water were free from this disease.

In summing up our present knowledge upon the removal of pathogenic bacteria from drinking water, we may state that, in addition to the experience of certain European cities, the Lawrence investigations, covering a period of more than five years and including the bacterial examination of more than 11,000 samples of water, indicate that it is entirely practicable to construct filters which will purify water economically and remove more than 99 per cent. of the bacteria in the unfiltered water.

THE METROPOLITAN SEWERAGE SYSTEM.[1]

By HOWARD A. CARSON, Engineer Metropolitan Sewerage Commission.

Read December 14, 1893.

The cities, towns, and separate districts of Boston proper, Cambridge, Charlestown, Somerville, Chelsea, East Boston, Brookline, Brighton, Everett, Winthrop, Watertown, Newton, Waltham, Malden, Melrose, Stoneham, Winchester, Woburn, Medford, Arlington, and Belmont are grouped closely together, as is well known. Excluding Boston proper, South Boston, and some other districts tributary to the intercepting sewers mainly completed nine years ago and shortly to be alluded to, they have an area of about 130 square miles and had a population in 1890 of 395,326.

The eight cities first named have had sewers for a long time; the next six towns and cities have had sewers for a few years; the others have few or none, but probably will have in the very early future. The eight cities first named discharge their sewers, except so far as they have been intercepted, into the nearest estuary, basin, or other tide water. Large areas of mud flats were uncovered by the low tide and gave off during much of the year offensive smells. Years ago this condition of things gave strong offense to the citizens of this area, and it was believed to be dangerous to the public health. Boards of health, many physicians, and other citizens remonstrated, and the question of affording relief was vigorously agitated. In 1875 a commission consisting of Civil Engineers E. S. Chesbrough and Moses Lane and Dr. Charles Folsom outlined a scheme of relief. They proposed two main drainage systems: one for that part of Boston south of the Charles River and for Brookline, having its outlet at Moon Island; another for Cambridge, Somerville, Charlestown, Chelsea, and East Boston, having its outlet at Shirley Gut.

[1] This sketch was prepared in the midst of pressing work. In making it the writer borrowed freely from his annual and other reports.

A portion of the former system, somewhat modified in route, was adopted. Work was begun upon it in September, 1877, and between six and seven years later it was partly completed and put in operation. This system is known as the Boston Main Drainage. It consists essentially of intercepting sewers which pass nearly around the peninsulas of Boston proper and South Boston and discharge into a trunk sewer which leads to Old Harbor Point. The intercepting sewers are low enough to intercept the flow of sewage in the local sewers, and are mainly lower than the mean low water of the sea. The sewage so intercepted flows to the pumping station at Old Harbor Point, and is there lifted high enough to be discharged at high water into the sea at Moon Island. The system embodies the fundamental ideas of the London system of intercepting sewers and main drainage completed nearly thirty years ago.

The Metropolitan Sewerage System is of a similar character. In its general features it is like that proposed by the commission of Chesbrough, Lane, and Folsom already referred to, but it takes the sewage from fourteen additional towns and cities. It consists, in reality, of two systems — one for Waltham, Newton, Watertown, Brighton, Brookline, and a part of Boston whose most easterly point is at the corner of Huntington Avenue and Gainsborough Street. This trunk sewer is a little over eight miles long and lies wholly south of the Charles River. It connects with the Boston system and finds an outlet at Moon Island. The much more extensive North Metropolitan System lies wholly north of the Charles River, and a considerable part of it lies north of the Mystic River. It has an outlet about one third of a mile south of the southerly end of Deer Island, or about a mile and a half beyond Shirley Gut outlet, proposed by the Chesbrough Commission.

Between 1875, which was the year of the Chesbrough Commission, and 1887 various studies were made by able commissions and able engineers for disposing of the sewage of the towns and cities outside of Boston proper here referred to. All of these studies helped to contribute to the final result. I cannot now take the space to further refer to them. In 1887 the matter was referred by the Legislature to the State Board of Health. This board considered three separate schemes — one for the discharge of crude sewage into a strong tidal current, whence it would be carried to sea beyond return; one for clarification by chemicals; and one for ground filtration. Three en-

gineers were engaged to each study one of the foregoing schemes. The writer was placed in charge of the studies of the first one.

The board finally concluded that the second scheme was too costly and not sufficiently effective and that the third would be impracticable; and they reported to the Legislature in January, 1889, in favor of the first scheme, which was estimated to cost, in round numbers, five million dollars.

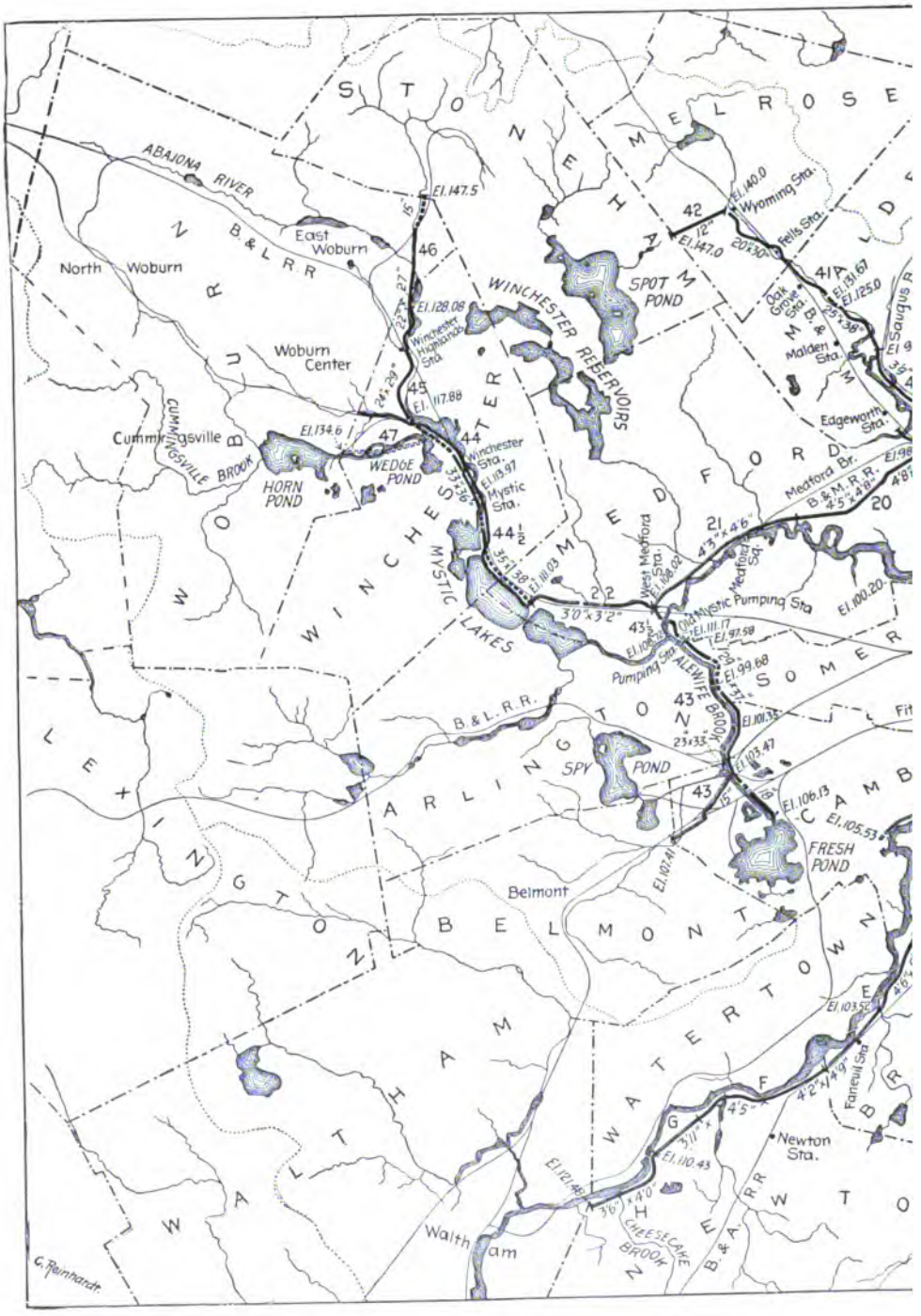
The Legislature passed an act, approved June 7, 1889, for a commission of three able and discreet men, to be appointed by the governor, to construct the Metropolitan Sewerage System substantially in accordance with the plan recommended. The Board of Metropolitan Sewerage Commissioners as at first organized consisted of Hosea Kingman, Tilly Haynes, and Dr. Robert T. Davis. In March, 1892, Harvey N. Collison succeeded Dr. Davis. The board organized in September, 1889, and engaged the writer as engineer in the latter part of October. The winter and spring of 1889–90 were spent in making surveys, studies, and plans. The work of construction began the latter part of May, 1890.

The Metropolitan Sewer is designed to carry mainly house sewage. Its capacity is based on the estimated population in the year 1930, and is about 225 gallons per head per day for that population. If it were to be made large enough to take roof water at the rate, say, of two and one half inches in five hours from the territory tributary to it, its carrying capacity would have to be increased between four and five times; and if it were designed to carry rain water from the whole surface, it would, of course, have to be much larger still.

The Metropolitan Sewer south of the Charles River has at Gainsborough Street, in Boston, a diameter of six feet six inches, which gradually diminishes in size, and eight miles above, at Waltham, is only three feet six inches by four feet in diameter. It has a fall most of the way of about two feet to the mile. The Charles River line was completed early in the spring of 1892, and has been in operation ever since.

The North Metropolitan System is now so far advanced that it may possibly be completed and in operation by the end of the following year.

The North Metropolitan Sewer for the lower five miles has an average diameter of a little more than nine feet, and has a fall of about one and three quarters feet to the mile. This system has various


ABAJONA RIVER
North Woburn
East Woburn
Woburn Center
Cummingsville
CUMMINGSVILLE BROOK
HORN POND
WEDGE POND
WINCHESTER RESERVOIRS
SPOT POND
MYSTIC LAKES
ALEWIFE BROOK
SPY POND
FRESH POND
Belmont
Newton Sta.
Waltham
CHEESECAKE BROOK
Wyoming Sta.
Wells Sta.
Oak Grove Sta.
Malden Sta.
Edgewater Sta.
Medford Br. B & M.R.R.
West Medford Sta.
Mystic Pumping Sta.
Pumping Sta.
Fanevil Sta.
B & L.R.R.
B & A.R.R.
WOBURN
STONEHAM
MELROSE
MEDFORD
SOMERVILLE
ARLINGTON
LEXINGTON
BELMONT
WALTHAM
WATERTOWN
CAMBRIDGE
El.147.5
El.128.08
El.117.88
El.134.6
El.113.97
El.111.03
El.111.17
El.97.58
El.99.68
El.101.38
El.103.47
El.106.13
El.105.53
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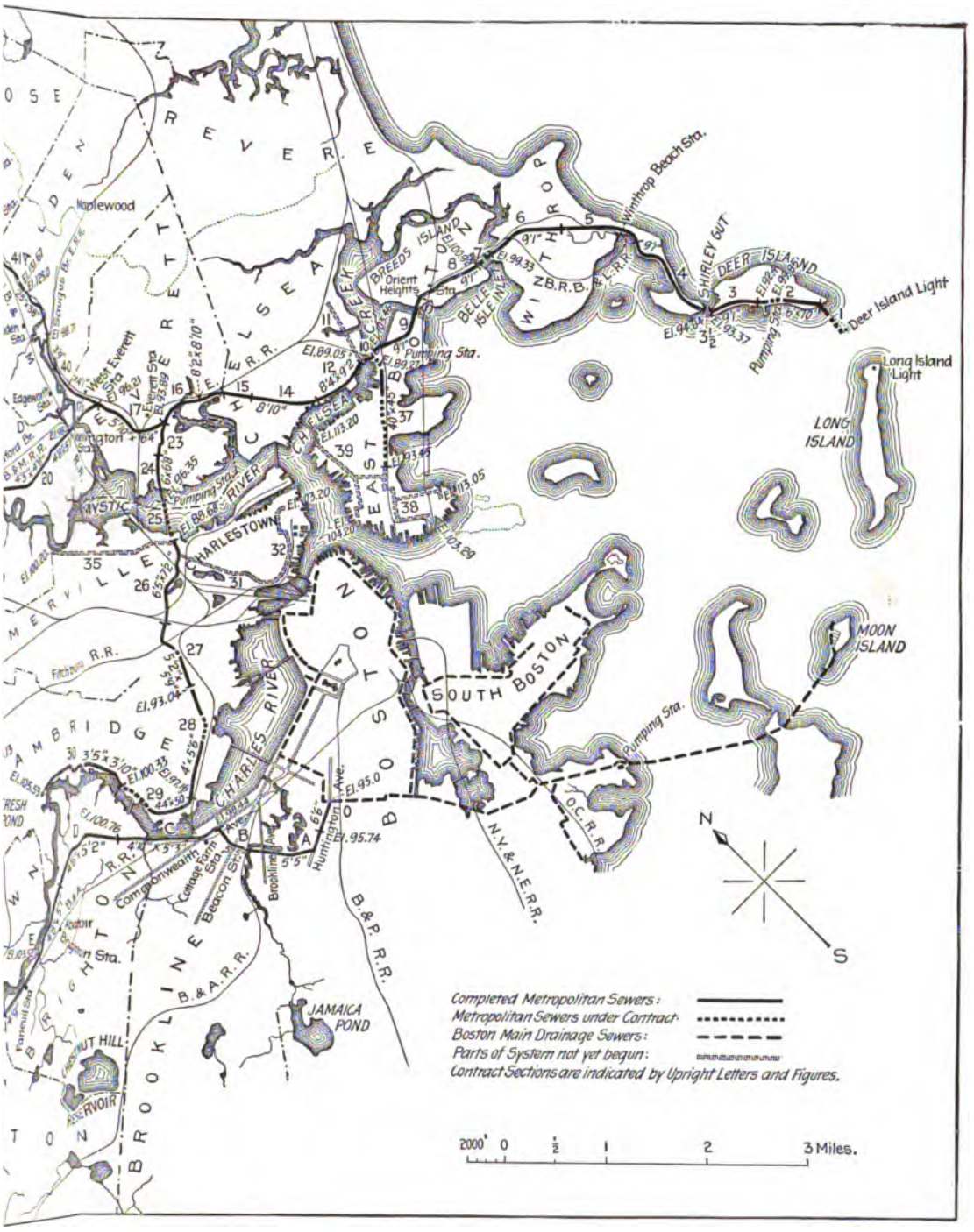

Maplewood
Winthrop Beach Sta.
SHIRLEY GUT
DEER ISLAND
Deer Island Light
Long Island Light
LONG ISLAND
MOON ISLAND
BREEDS ISLAND
Orient Heights Sta.
BELLE ISLE INLET
Pumping Sta.
CHELSEA CREEK
CHELSEA
EAST BOSTON
CHARLESTOWN
MYSTIC RIVER
SOUTH BOSTON
CHARLES RIVER
Fitchburg R.R.
Commonwealth Ave.
Beacon St.
Brookline Ave.
Huntington Ave.
Cottage Farm Sta.
B.&A.R.R.
B.&P.R.R.
N.Y.&N.E.R.R.
O.C.R.R.
JAMAICA POND
CHESTNUT HILL RESERVOIR
BROOKLINE
BOSTON
CAMBRIDGE
WINTHROP
REVERE
CHELSEA
MEDFORD
SOMERVILLE
WATERTOWN
N
S
Completed Metropolitan Sewers:
Metropolitan Sewers under Contract:
Boston Main Drainage Sewers:
Parts of System not yet begun:
Contract Sections are indicated by Upright Letters and Figures.
2000' 0 1/2 1 2 3 Miles.

branches. One begins in Stoneham, in Montvale Avenue, near Oakland Station, about eighteen miles from Deer Island, where it is to receive most of the sewage from Stoneham. It follows down the valley of the Abbajona River to a point below Winchester, and then in the bed of the old Middlesex Canal to a point near the dam between the upper and lower Mystic lakes. Here it is joined by the old Mystic Valley Sewer, built some fifteen years ago by the city of Boston. The Cummingsville Branch (to be built by the board) will discharge into the old sewer. This old Mystic Valley Sewer has been purchased by the board and adopted as part of the system, to take most of the sewage from Woburn and some from Winchester. The Metropolitan Sewer continues down the valley near the Lowell Railroad to West Medford. At West Medford it receives the Alewife Brook Branch, which is designed to take the sewage from Belmont, Arlington, and part of that from Cambridge, Somerville, and Medford. Continuing through Medford, the Metropolitan Sewer receives at Wellington the so-called Edgeworth Branch, and will there take the sewage from Edgeworth and the west side of Malden.

The Metropolitan Sewer passes under the Malden River by a depressed curve or inverted siphon and joins, near East Everett Station, the branch from Stoneham, Melrose, and Malden. About three quarters of a mile further on, in the marsh near the Everett Station, it joins the so-called Cambridge Branch, which is designed to take the sewage from Cambridge, Somerville, Charlestown, and parts of Medford and Everett. It then passes through a part of Chelsea and around a part of the water front. Near Eastern Avenue it receives a branch, which is to intercept certain Chelsea sewers discharging into Chelsea Creek north of the railroad bridge. The sewer then passes by a siphon under Chelsea Creek to the proposed pumping station in East Boston. At this pumping station is received the system of intercepting sewers from East Boston, and the sewer here takes an upward step of sixteen feet. It then passes through a part of East Boston proper and Breed's Island, and under Belle Isle Inlet by another siphon; passes through Winthrop, under Shirley Gut by another inverted siphon; and continues on its way to the middle of the western shore of Deer Island. Here another pumping station is reached and the sewage is to be lifted to such varying heights as are necessary to discharge into the sea at different stages of the tide. The outfall sewer from this station continues near the western shore

of Deer Island to its southerly end, and then passes about two thousand feet out into the sea to a point where the sewage is to be discharged.

The so-called Cambridge Branch begins in Mount Auburn Street, Cambridge, some fifteen miles distant from the Deer Island outlet. The route of this Metropolitan Sewer lies mostly in streets near the bank of the Charles River. It will pass under and intercept the sewers which now discharge into that river. It passes under the McLean Asylum grounds in Somerville, and in Sullivan Square, Charlestown, it receives the Charlestown Branch. At Arlington Street, near Alford Street, it will receive a branch designed to take the sewage from parts of Medford and Somerville. The route next lies under the Mystic River on the east side of the Malden Bridge. Near the middle of Mystic River there is to be a pumping station, where the sewage will be lifted about nine feet.

The general route of the sewers is indicated upon the map. The sizes and the elevations above the datum plane are also indicated. The datum plane in question lies about one hundred feet below mean low water of Boston Harbor.

LOCATION OF PUMPING STATIONS.

There are four pumping stations on the North Metropolitan System — the three already alluded to and a small one on the Alewife Brook Branch in Somerville, near West Medford. The question has been asked, "Would it not be a better arrangement to concentrate all these pumping stations at Deer Island?" The discharge of the sewage is to be into the sea, whose average high level is about the same as the salt marshes which are everywhere to be seen about Boston. In order that the sewage shall flow towards the outlet the hydraulic gradient of the sewers must have an inclination in that direction. If the ground on which the dwellings are placed were high enough and sloped towards the sea, pumping might, of course, be dispensed with altogether. As a matter of fact, however, much of the district miles away from Deer Island is lower than Deer Island itself. The Metropolitan Sewer, for instance, where it passes under the local sewer in Hawthorne Street, Cambridge, near the Charles River, is only four feet above the mean low level of the sea, and from its inclination it of course gets lower and lower as we pass in the direction in which the sewage flows.

FIGURE 1. MYSTIC RIVER SIPHON, SECTION 25.

If there were no lift at Charlestown the three miles of sewer between that point and East Boston would be eight feet deeper than at present. This stretch of sewer already has an average depth of about twenty-five feet, and the cost of excavation if made eight feet deeper would be enormously increased. If the sewer still kept on, without a pumping station at East Boston, all that portion between East Boston and Deer Island would be twenty-four or twenty-five feet deeper than at present. The increased cost of the sewer placed so much deeper would have been counted by hundreds of thousands of dollars. The saving in cost of construction, however, is not the whole advantage gained by separating the pumping stations. Without such separation the work of pumping would have been very much increased; for it is clear that all the sewage from districts west of the East Boston Pumping Station, except that from Cambridge, Somerville, and Charlestown, would have been allowed to fall eight feet lower than as now arranged, and forever be pumped from this eight-feet lower level, and that all of the sewage from districts east of the East Boston Pumping Station would have to be pumped from a depth twenty-four feet greater than is necessary by the present arrangement.

It is thus seen that the use of several pumping stations does not increase the total work of pumping measured in foot pounds or otherwise, but, on the contrary, largely decreases it. A further advantage is that the comparatively low lift at each place allows the use of centrifugal pumps. In the matter of weight, space, liability to accidents, and especially in cost of pumps and cost of foundations and buildings, the advantages are in favor of centrifugal as compared with reciprocating pumps. The former, also, from the absence of valves, are better adapted to pumping sewage. Taking into account interest and depreciation on plant and buildings, as well as consumption of fuel and all other items of expense, it is found in the case under consideration that three low-lift stations with centrifugal pumps are at least as economical as one high-lift station with reciprocating pumps. It has already been shown that the cost of sewers in the former case is very much less. Studies were also made for concentrating the pumping at East Boston and using either force mains or a high masonry sewer between East Boston and the point of discharge. It was concluded that the cost of each of these latter designs would have been as great as the cost of the deep sewer and concentration at Deer Island previously alluded to, and with the disadvantage that neither

would be available for taking the sewage from points east of the East Boston Station.

RESERVOIRS AND DIRECT CONTINUOUS DISCHARGES.

The sewage from the Boston Intercepting System is not continuously discharged. There is a reservoir at Moon Island in which the sewage is stored during the flood and portions of the ebb tide. It seems probable that a reservoir will not be needed on the North Metropolitan Sewerage System for years, if at all. Deer Island is about two and one half miles nearer the ocean, measured in the direction of the current, than the outlet of Moon Island Reservoir. Experiments and observations appear to demonstrate that no nuisance would be caused for years, if ever, by discharging continuously near Deer Island Beacon. The saving in interest alone by direct discharge would within twenty years pay the cost of a reservoir and an additional outlet. The cost of pumping and other items of expense will also be lessened by omitting a reservoir. It may also be noted that storing sewage for a few hours may give an offensive smell which it would not otherwise have.

If a reservoir shall be needed it will cost no more to build at a later time, and therefore, in any event, such building should be postponed until the effect of discharging the sewage continuously is clearly seen.

PUMPING ENGINES.

Two engines each, with boilers, piping, etc., are now being built for the proposed pumping stations at Deer Island, East Boston, and Charlestown. Regarding the plant for the first two stations: Each engine is to be capable of easily raising 70 cubic feet of sewage 19 feet vertically above the level of the sewage pump well and to raise to greater heights up to 25 feet quantities of sewage inversely proportional to such lifts. Each is also to be capable of pumping at as low a rate as 15 cubic feet per second and at all rates between 15 and 70 cubic feet per second. The pumps will be of the centrifugal type, with vertical shafts. The suction and discharge pipes will be each 48 inches in diameter and intended to run at speeds varying from sixty to one hundred revolutions per minute, according to the amount of sewage and the height to which it is lifted. The pump wheel is to be driven by a triple expansion engine of the Corliss type. The diam-

eter of the cylinders will be 13½″, 24″, and 34″, with a 30″ stroke. Condensers will be used. The discharge channels from the pumps will contain check valves to prevent any backward flow when the pumps are stopped. The inlet channels from the pump wells will be provided with gate valves to admit of closing off the passage when desirable.

The quantity of sewage arriving at the Charlestown Pumping Stations will be about half that at the East Boston or Deer Island Pumping Station. The engines will be similar in general design to those for East Boston and Deer Island. Each pump will have a capacity of 35 cubic feet per second raised 11 feet high. The suction and discharge openings will be 36″ in diameter. The diameter of the pump wheels will be about 8 feet. The cylinders will be 10″, 18″, and 36″, with a 30″ stroke.

CONSTRUCTION.

A small portion of the work on the sewerage system has been shallow. In general, however, much deep and difficult excavation has occurred, requiring skill, ingenuity, and fertility in resources on the part of the engineers and contractors. In most of the excavation machinery of some kind has been employed, as, for instance, the boom derrick, the A frame, the incline, but it has been mostly done by trench machines.

Sections 1 (Deer Island Outlet), 3½ (Shirley Gut Siphon), 10 (siphon under Chelsea River), 25 (siphon under Mystic River, Charlestown), and other parts involving much more than ordinary risk, and on which it might be necessary to change the plans during construction, have been or are now being done by foremen and laborers directly under the supervision of the engineering department instead of by contract. Some account of the work on two of these sections will now be given.

SECTION 25, MYSTIC RIVER SIPHON.

A sewer tunnel is now being built under Mystic River parallel with and about 58 feet from Malden Bridge, and when completed it will extend from Tuft's Mill Pond to the site of the Charlestown Pumping Station, a distance of about 862 feet. It has now nearly reached the pumping station. The bore of the tunnel before the brickwork is put in is about 7 feet in diameter. The average depth

of the bottom of the tunnel excavation below the floor of Malden Bridge is about 45 feet. The average thickness of the earth over the crown of the arch is about 15 feet. At some places it is only about 6 feet (Figure 1, after page 298). A shaft 49 feet deep is located at a point about 50 feet from Mystic River at the southerly end of Malden Bridge.

Large quantities of sulphureted hydrogen were encountered, so that the men were able to remain in it but for about an hour at a time. The annoyance from the sulphureted hydrogen was partially alleviated by forcing a volume of fresh air into the shaft by means of air compressors. About one in the morning of June 6 a pocket of carbonic acid gas was struck. The gas flowed into the trench and suffocated two men almost instantly and overcame a foreman who went to their assistance. The foreman was rescued, and recovered in a day or two.

After a trial of various measures which proved only partially remedial a vertical lock was put in the shaft, and the sinking finished by the use of compressed air. The shaft was down June 30 and the heading commenced. A horizontal air lock was put in the tunnel, and excavation under pressure began July 24. The roof of the tunnel is kept in place as digging progresses by steel flanged plates bolted together and supported temporarily by screw braces. These plates usually extend about one third of the way around the periphery of the tunnel bore Sometimes in treacherous earth they are made to extend much further. The tunnel invert is usually one foot in thickness. The arch varies from 1 foot to 2 feet in thickness and averages about 1 foot 3 inches. The material excavated in tunneling has been mainly in clay, but partly of sand. During the progress of this work bubbles of air have been seen to freely escape from the water above the tunnel. On the last day of October the agitation near the end of the tunnel as then excavated was more violent than usual, and two compressors were required to keep up the pressure. The men stopped work at midnight and went outside to eat. On their return the leak was found to be greater than before. They made some effort to stop it, but as the leak was increasing at a dangerous rate were forced to retreat a distance of more than six hundred feet to the interior of the air lock and close its door. The water was then knee deep in the tunnel and lock and rising fast. Ten minutes thereafter the tunnel was filled with mud and water. Fortunately no lives

were lost. The next day soundings revealed a crater-shaped hole near the end of the tunnel. Repairs were begun by filling the hole with clay. A canvas sail was obtained and weighted on one side. It was sunk in such a manner that the current caused the canvas to spread over the clay-filled hole. The canvas was then covered with clay. The tunnel was soon afterwards pumped out, and progress has since been uninterrupted.

SECTION $3\frac{1}{2}$, SHIRLEY GUT SIPHON.

Shirley Gut is the name given to a narrow strait which separates Deer Island from Winthrop. At the point selected for the sewer crossing it is about 315 feet wide at mean high water and has a width of about 105 feet at low water. The tidal current, which is noted for its swiftness at this point, practically never ceases. The depth of water at mean high tide in the middle of the Gut is about 25 feet. The shores and bed consist of gravel and sand down to respective depths on the Deer Island and Point Shirley sides of about 26 and 66 feet below mean low water, where clay is found.

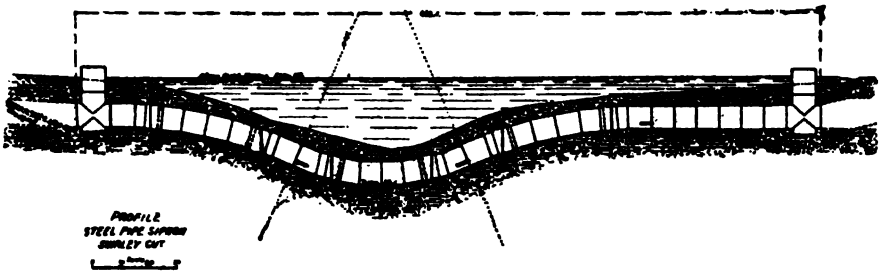


FIG 2. PROFILE OF SHIRLEY GUT SIPHON.

It was necessary that the sewer passing under the Gut (connecting the sewer already laid on the Winthrop side with that on the Deer Island side) should be in the shape of a depressed curve (Figure 2) or inverted siphon, having its axis in the middle of the Gut about 22 feet lower than the axis of the sewer on the Winthrop side.

This was necessary in order not to impair navigation, and it involved digging a trench beneath from 12 to 18 feet below its bed. Various methods of construction had been suggested. The best of all, so far as the sewer is concerned, would have been to make a permanent causeway across and build the sewer with a straight grade, and

thus dispense with the siphon. This was at one time considered by the board. A hearing was had on the subject, but, as considerable opposition was met, it was thought that seeking the necessary Congressional and State legislation would involve too much delay, with considerable chance of its being rejected.

A practicable method would have been to descend in a shaft about 70 feet on the Winthrop side into the clay, tunnel under the Gut in this clay, and ascend on the Deer Island side. It has been constantly kept in view in designing all parts of the Metropolitan System to so place the sewer as to admit of its examination with little difficulty at any time. The objection to the method of deep tunneling just referred to is that its great depth would make it slow and expensive work pumping out the siphon for examination.

It was concluded, on the whole, that it would be better for all concerned that the State should incur the risks of the work. It was therefore done directly under the direction of the engineering department.

After a careful study and consideration of the various questions involved it was concluded that a single line of pipe having the same capacity as a double line previously proposed would be simpler and more reliable in management when the works were in actual use, although it might possibly be more costly in first construction. This led to the plan of a line of sewer across the Gut formed of masonry 12 inches in thickness surrounded by a shell of steel three eighths of an inch in thickness. The use of the steel shell was for strength and tightness in the process of laying. It was not necessary that it should prove permanent. A branch was to be provided at each side of the Gut so that, should experience in actual maintenance and operation of the system show it to be desirable, an additional line could be laid across in the future when found to be necessary.

It was at first proposed to lay the steel pipe in the trench in sections of 50 or 60 feet, employ a diver to connect the sections, then pump out the interior and lay the 12-inch shell of brickwork therein. With the pressure of water that would exist under these conditions steel shells far thicker than those proposed would collapse before the water could be pumped out. To prevent this it was proposed that the pipes should be braced interiorly with closely placed wooden-braced rings, to be placed in the pipes before they were moved from the shore. Further consideration led to making use of the brick-

FIGURE 3. CENTER SECTION, SHIRLEY GUT SIPHON.

work itself for bracing the pipes, although their weight would then be increased sixfold.

The first step in carrying out this design was to build across the Gut a bulkhead whose maximum height was about 27.5 feet, with a length of about 467 feet, and with its top about 12.7 feet above mean low water. This bulkhead or dam was built of sufficient strength to resist the pressure of the tidal current and to successfully withstand many storms that have since occurred. This dam stopped the swift tidal current and enabled a dredge to operate. The trench dredged in this comparatively still water stood fairly well. The heavy storms of August partially filled it, and considerable redredging was done.

The steel pipes, in sections of 48 to 68 feet, were placed near high-water mark on the Winthrop shore. They were lined with brickwork about 13 inches thick and bulkheads were constructed at the end of each section. These bulkheads were 8 inches thick, of hard pine timber, and were calked and pitched by ship calkers. As a further precaution they were covered with sheets of rubber, which were cemented to the steel outer skins of the sections. The bulkheads were strongly secured to the masonry of the pipes. To test the tightness of these pipes an attempt was made to exhaust the air from the interior of them by means of small steam ejectors. After several hours it was found that the partial vacuum, as indicated by an ordinary vacuum gauge, was only about one inch of mercury. The rubber sheets were then taken from the ends of the pipe and the ends covered with Portland cement mortar. This mortar after it was set was painted with asphalt, and various joints of the steel structure were examined and leaks found and stopped and the pipes made practically tight. Figure 3 shows the center section in process of construction.

On the afternoon ebb tide of September 13 and the morning ebb of the 14th the middle section was moved on rollers to low-water mark by building movers, Cavanagh and Sons.

In the mean time the dredging scow, 33 feet 8 inches wide, 79 feet long, and 6 feet 6 inches deep, had been fitted with two overhanging trestles or shears, with specially made blocks and tackle for hoisting, holding, and lowering the pipe. These shears were placed on the side of the dredge about 35 feet apart, and so arranged that they could be later moved to other appropriate distances for handling the following pipes. About 12.30 o'clock P.M., on September 14, the tide then lacking about one hour from high water, the dredge was anchored to

the southward and the hoisting tackles were attached to steel straps toward the two ends of the pipe. The four drums of the two hoisting engines were then slowly set winding. In this manner the pipe was partly lifted and partly pulled from the 12-inch square timbers and

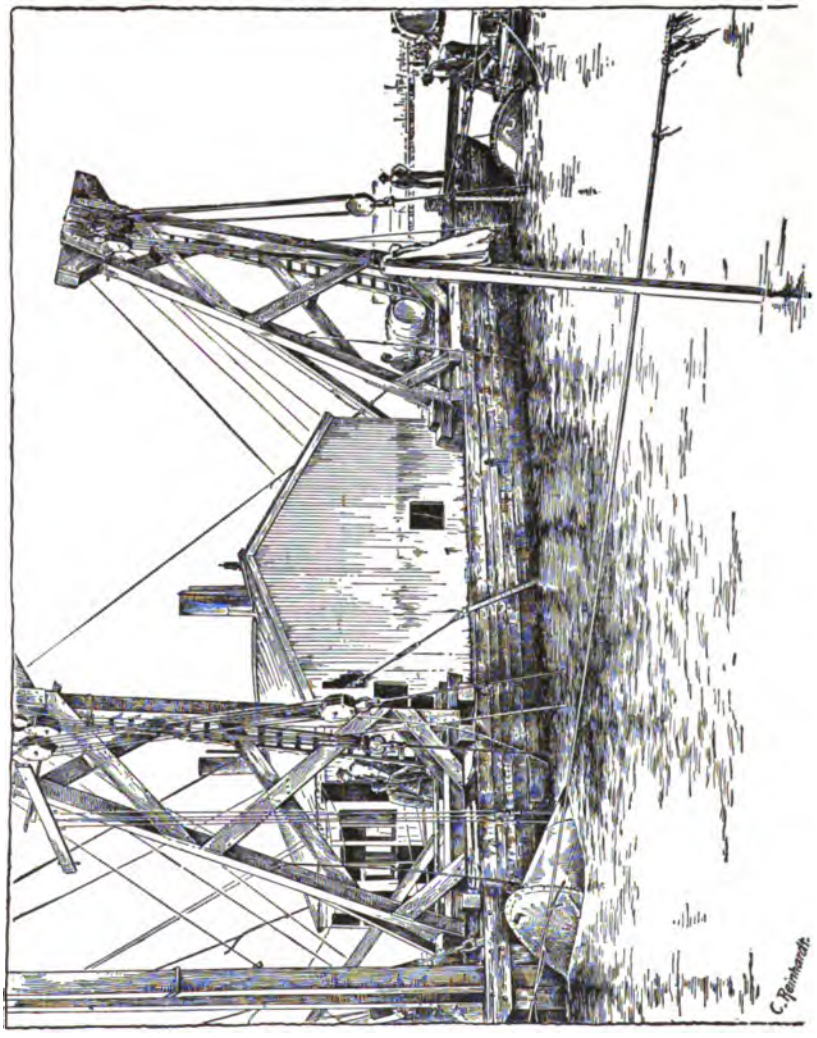


FIG. 4. CENTER SECTION READY TO BE LOWERED.

about eighty hard wood rollers on which it rested. The rollers and blocking immediately rose to the surface, covering the vicinity with floating wood. The dredge and the pipe were then pulled out to deeper water and the pipe slightly lowered. It was found that the

FIGURE 5. MOVING WINTHROP END SECTION, SHIRLEY GUT SIPHON.

weight of the pipe in salt water was just about equal to the displacement and when lowered it sank nearly but not quite to submersion. The weight in air of this pipe was about 225,000 pounds.

The scow and pipe were then moved so that the latter was nearly over the position which it was finally to occupy. As has been seen by the profile, the pipe was bow-shaped, and when moved from the shore to near its final position its symmetrical plane was horizontal. The pipe had now to be revolved ninety degrees, so that its symmetrical plane would become vertical with the concave side of the pipe uppermost (Figure 4). This was done by hoisting on two ends of the

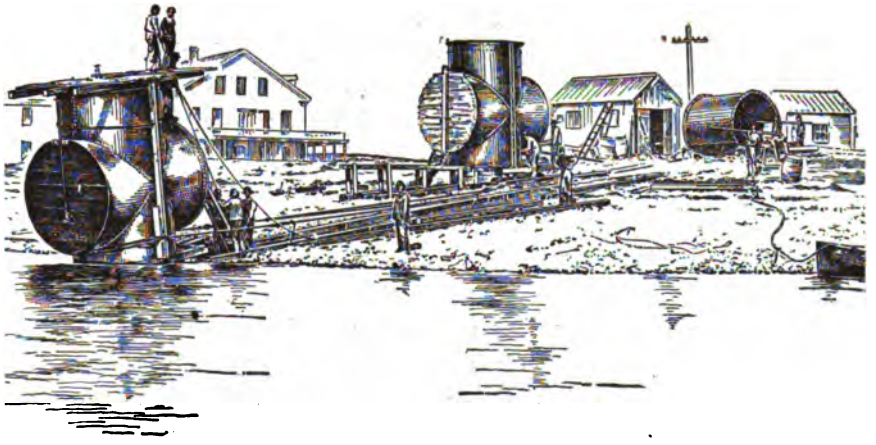


FIG. 6. MANHOLE SECTIONS ON BEACH.

straps and lowering on the other two ends. After letting some water into the pipe through a small gate and increasing its weight with a few sand bags it was lowered to its final position and rested on two accurately placed cross sills provided for that purpose. Its true position in plan as it was lowered was determined by vertical wires which were stretched from points on the middle plane of the pipe to pulleys on the hoisting rig. Its descent to its true position in plan was facilitated and partly brought about by two ropes, one at each end of the pipe. These ropes passed under pulleys anchored in the bottom of the Gut in the exact central line of the sewer. The ropes ascended

to the top, were led to the scow, and were kept in tension by six or eight men to each rope.

The other three long pipes were on following days successfully moved down the beach (Figure 5), carried out into the Gut, partially revolved, lowered to the bottom, and bolted one to another. This latter work was done by divers.

Many details were provided to compel each pipe, though under water and out of sight, to go precisely to its proper place and to give evidence above the surface that this was being accomplished. All these devices resulted in reducing the work of the divers to the lowest practicable terms.

Figure 6 shows one of the short manhole sections as it is being moved down the beach, and Figure 7 shows it on its way from the beach to its position in the siphon.

The interior bulkheads have now all been removed from the siphon, and the short spaces between the pipes at the joints formerly occupied by the bulkheads have been filled with masonry. The pipes were found to be tight and in an exceedingly satisfactory condition.

The various assistants and foremen connected with the Shirley Gut Siphon took great interest in thinking out and discussing with the writer the necessary details, and our success was largely due to their intelligent work.

It can be said further that any measure of success which may be achieved on the system as a whole will be largely due to the earnest and intelligent work of the engineering and other assistants.

FIGURE 7. MANHOLE SECTION, FLOATING, SHIRLEY GUT SIPHON.

SOME EXPERIMENTS FOR DETERMINING THE REFRACTORINESS OF FIRE-CLAYS.[1]

By H. O. HOFMAN and C. D. DEMOND.

Received December 18, 1893.

There are two methods of determining the fusibility or refractoriness of fire-clays, the theoretical and the experimental. In the former, conclusions are drawn from the chemical composition; in the latter, from the changes which the clay undergoes when subjected to intense heat. It is well to use both methods, beginning with the actual heat-test and explaining the results obtained from this by the help of the chemical analysis. In discussing the subject, however, it is better to reverse this order.

I. The Theoretical Method.[2]

Leaving out the hygroscopic and combined waters and any organic matter, as not directly affecting the fire-resisting property, the refractory constituents of fire-clay are alumina and silica, and the fluxing constituents magnesia, lime, soda, potash, and ferric oxide. According to Bischof,[3] alumina is the least fusible component, and silica follows close upon it. If, however, a mixture of the two be heated, it will be found that its melting point is much lower than that of alumina, as a silicate will then have been formed. The way in which silica affects the refractoriness of alumina has been strikingly presented by Seger[4] in a diagram reproduced in Figure 1. The abscissæ represent the melting points of Seger cones Nos. 26 to 36; the ordi-

[1] Read at the Virginia Beach Meeting of the American Institute of Mining Engineers, February, 1894.

[2] C. Bischof, Die feuerfesten Thone, Leipsic, 1876, p. 71.

R. Keller (Revised by C. Bischof), Ueber die Fabrication und Anwendung feuerfester Steine, Aix-la-Chapelle, 1890; a lecture, pp. 1–16.

Bruno Kerl, Handbuch der gesammten Thonwaarenindustrie, Brunswick, 1879, pp. 59 and 71.

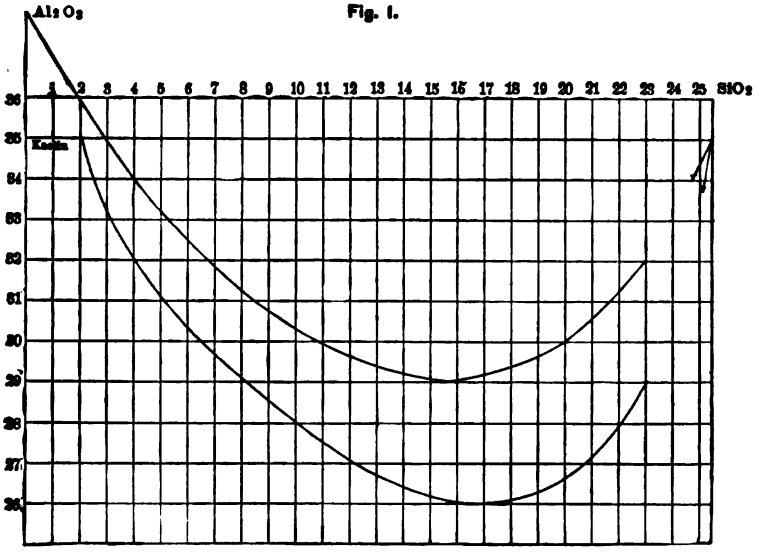
J. Post, Chemisch-technische Analyse, Brunswick, 1890–91, Vol. II, p. 48.

[3] Dinglers Polyt. Jour., Vol. CLXIX., pp. 353, 455; Vol. CLXX., p. 43.

[4] Thonindustrie-Zeitung, 1893, p. 391.

nates, the relative amounts of alumina and silica in the mixture. The least fusible consists of one molecule of alumina and two molecules of silica, and melts, as shown by the upper curve, at a temperature indicated by Seger cone No. 36. The fusibility is seen to increase with the amount of silica up to the proportion $1Al_2O_3 : 17SiO_2$, and then to decrease (on account of the preponderance of silica, which cannot combine to form a silicate), until, finally, the effect of the alumina has disappeared and the melting point of silica, equal to that of Seger cone No. 35, has been reached. The lower curve shows in a similar way the effect of silica on the fusibility of the kaolin from Zettlitz, Bohemia (see Table I, page 304). The practical deduction is that the refractoriness of a fire-clay increases with the amount of alumina it contains.

Fig. 1.



FUSIBILITY OF ALUMINA-SILICA AND KAOLIN-SILICA MIXTURES.

The effects of the fluxing constituents have been studied by Bischof[1] and Richters.[2] The latter, in 1868, propounded the law that their fluxing property is inversely proportional to their molecular weights; thus, 40 magnesia would have a slagging effect equivalent to that of 56 lime, 62 soda, 94 potash or 160 ferric oxide. While Bis-

[1] Dinglers Polyt. Jour., Vol. CLXV, p. 378; Vol. CXCVI, pp. 438, 525; Vol. CXCVIII, p. 407. Thonindustrie-Zeitung, 1885, p. 13.

[2] Dinglers Polyt. Jour., Vol. CXCI, pp. 59, 150, 229; Vol. CXCVII, p. 268.

chof[1] supports this view to-day, it is attacked by Seger,[2] who maintains that ferric oxide has a stronger slagging effect than any other of the four bases. Whatever may be the precise order in which these bases are to be placed, one thing is settled, namely, that if their total amount exceeds 6 per cent. of the ignited clay, this cannot be classed any longer as refractory.

To sum up, the fire-resisting power of a clay, considered from a chemical point of view, depends first upon the character of the fluxing constituents and their relation to alumina and silica, and, secondly, on the relation of alumina and silica to one another. Bischof[3] arrives at the refractory character of a clay by what he calls the refractory quotient, which he obtains by dividing the quotient of the oxygen of the fluxes into that of the alumina by the quotient of the oxygen of the alumina into that of the silica.[4]

In the seven standard fire-clays which he selected as types (see Table I, which has been slightly changed from the original) this refractory quotient is 13.95 with the most refractory clay — No. 1, from Saarau, Silesia — and decreases with the fire-resisting power until it reaches in clay No. 7, from Niederpleis, Nassau, the figure 1.64, and a clay the refractory quotient of which is less than 1 (equal to Seger cone No. 26) is not to be classed any longer as refractory. Taking as an example clay No. 2 of Table I — the kaolin from Zettlitz, Bohemia — the refractory quotient would be

$$\text{R. Q. B.} = \frac{\text{O in } Al_2O_3}{\text{O in RO}} \div \frac{\text{O in } SiO_2}{\text{O in } Al_2O_3} = \frac{17.960}{1.401} \div \frac{24.363}{17.960} = \frac{12.82}{1.35} = 9.49.$$

[1] See Keller-Bischof, op. cit., p. 7.

[2] Thonindustrie-Zeitung, 1893, p. 392.

[3] Dinglers Polyt. Jour., Vol. CXCIV, p. 420; Vol. CXCVI, pp. 438, 447, 525; Vol. CC, pp. 110, 289. Thonindustrie-Zeitung, 1888, pp. 38, 50.

[4] When Bischof made his researches silica was written SiO_3. The quotient, expressed as above, would have had the form $\frac{\text{O in } Al_2O_3}{\text{O in RO}} \div \frac{\text{O in } SiO_3}{\text{O in } Al_2O_3}$, and in carrying out any calculations the oxygen of RO would have to be multiplied by three. For Seger's refractory quotient (see later) the ratio $\frac{\text{O in } SiO_3}{\text{O in RO}}$ is required; here also the oxygen of RO has to be multiplied by three. To-day the old mode of expressing the value is retained and the new atomic weights are adopted.

To find the oxygen in the components of clay each is multiplied by its coefficient, as $Al_2O_3 \times 0.466$, $SiO_2 \times 0.533$, $MgO \times 0.400$, $CaO \times 0.2857$, $K_2O \times 0.1698$, $FeO \times 0.222$.

Iron, present in the clay usually as ferric oxide, is figured as ferrous oxide, $Fe_2O_3 \times 0.9 = 2FeO$. Soda is figured as potassa, $62Na_2O$ being equivalent to $94K_2O$.

$$\frac{\text{O in } Al_2O_3}{\text{O in RO}} \div \frac{\text{O in } SiO_2}{\text{O in } Al_2O_3}.$$

TABLE I.—BISCHOF'S STANDARD FIRE-CLAYS.

Fire-Clay.		Al_2O_3.		SiO_2.			RO.						
Name and Source.	No.	Total per cent.	Oxygen per cent.	Combined per cent.	Non-combined per cent.	Total per cent.	Oxygen per cent.	MgO per cent.	CaO per cent.	K_2O per cent.	Fe_2O_3 per cent.	Total per cent.	Oxygen per cent.
Saarau, Silesia	I.	36.30	16.917	38.94	4.90	43.84	23.366	0.19	0 19	0.42	0.46	1.26	0.293
Zettlitz, Bohemia	II.	38.54	17.960	40.53	5.15	45.68	24.363	0.38	0.08	0.66	0.90	2.02	0.467
Andennes, Belgium	III.	34.78	16.208	39.69	9.95	49.64	26.457	0.41	0.68	0.41	1.80	3.30	0.778
Coblence, Rhen. Province . .	IV.	36.00	16.777	41.00	6.74	47.74	25.445	0.33	0.40	1.05	2 57	4.35	0 938
Grünstädt, Palatinate	V.	35.05	16.334	39.32	8.01	47.33	25.225	1.11	0.16	3.18	2 30	6.75	1 490
Cassel, Hesse	VI.	27.97	13.035	33.59	24.40	57.99	30.908	0.54	0.97	0.53	2.01	4.05	0.985
Niederpleis, Nassau	VII.	28.05	13.072	30.71	27.61	58.32	31.084	0.75	0.72	1.39	1.89	4.75	1.120

TABLE I. — *Concluded.*

Fire-Clays.		Loss by ignition, per cent.	O in Al_2O_3 divided by 3O in RO.	O in SiO_2 divided by 3O in RO.	O in SiO_2 divided by O in Al_2O_3.	Pyrometric Equation.	Refractory Quotient.		Relative Refractoriness.	Corresponding Seger Cone.
Name and Source.	No.						Bischof R. Q. B.	Seger R. Q. S.		
Saarau, Silesia	I.	17.78	19.25	26.50	1.38	$19.25(Al_2O_3, 1.38SiO_2) + RO$	13.95	33.15	100	36
Zettlitz, Bohemia . . .	II.	13.00	12.82	17.31	1.35	$12.82(Al_2O_3, 1.35SiO_2) + RO$	9.49	22.31	60–70	35
Andennes, Belgium . . .	III.	12.00	6.86	11.20	1.63	$6.86(Al_2O_3, 1.63SiO_2) + RO$	4.21	11.08	50	33
Coblence, Rhen. Province,	IV.	11.81	5.96	9.10	1.51	$5.96(Al_2O_3, 1.51SiO_2) + RO$	3.95	9.97	45	32
Grünstädt, Palatinate . .	V.	10.51	3.65	5.64	1.54	$3.65(Al_2O_3, 1.54SiO_2) + RO$	2.37	6.03	30	30
Cassel, Hesse	VI.	9.43	4.41	10.46	2.37	$4.41(Al_2O_3, 2.37SiO_2) + RO$	1.86	6.27	20	28
Niederpleis, Nassau . .	VII.	8.66	3.89	9.25	2.37	$3.89(Al_2O_3, 2.37SiO_2) + RO$	1.64	5.54	10	26

These figures embodied in Bischof's pyrometric formula for clay give

$$12.82\ (Al_2O_3,\ 1\ 35\ SiO_2) + 1\ RO.$$

Bischof's method has found pretty general acceptance within the necessary limitations. It is, however, questioned to some extent by Seger,[1] who says that while the refractoriness of a clay increases with the alumina and decreases with the silica, the proof is wanting that the decrease in refractoriness takes place in direct proportion to the amount of silica and the increase in proportion to the square of the alumina, and that, furthermore, the refractoriness does not depend solely upon the relation which silica and alumina bear to one another. He therefore recommends adding the ratio of fluxing constituent to alumina and that of fluxing constituent to silica, and multiplying this sum by the quotient obtained from dividing the latter into the former, thus:

$$\left(\frac{O \text{ in } Al_2O_3}{O \text{ in } RO} + \frac{O \text{ in } SiO_2}{O \text{ in } RO}\right) \times \left(\frac{O \text{ in } Al_2O_3}{O \text{ in } RO} \div \frac{O \text{ in } SiO_2}{O \text{ in } RO}\right).$$

Taking the same Zettlitz clay as example, Seger's refractory quotient would be:

$$\text{R. Q. S.} = (12.82 + 17.31)\ \frac{12.82}{17.31} = \frac{30.13}{1\ 35} = 22.31.$$

Bischof[2] does not consider Seger's refractory quotient an improvement on his own, and suggests that the older quotient be maintained until something better shall be discovered. Both quotients are used, Bischof's, however, being the more common one. In comparing the two by the standard clays (Table I), it will be seen that while the experimental results of both Bischof (relative refractoriness) and Seger (number of corresponding cone) agree with Bischof's refractory quotient, there is a discrepancy with Clay VI, which Seger's refractory quotient would make more refractory than Clay V. Something similar is to be noted in Table III, where Seger's refractory quotient makes the kaolin from Blanford, Massachusetts, less refractory than the clay from Mount Savage, Maryland, while the experiments of Tables IV and V prove the contrary to be the case. In the single series of experiments in Tables IV, V, and VI, both refractory quotients increase, on the whole, with the refractory values of the mixtures, but it has not

[1] Thonindustrie-Zeitung, 1877, pp. 290, 296; 1889, p. 332; 1893, p. 339.
[2] Thonindustrie-Zeitung, 1889, p. 331.

been possible to find the desirable regularity which was thought to exist. Nevertheless, the quotients have been embodied in the tables in order to furnish another means of judging of the refractory character of the clays and their mixtures made for experiment.

No deduction, however, made from the chemical analysis can have the force of a positive determination, because analysis necessarily ignores the physical constitution, whereas a coarse-grained clay is less fusible than a fine-grained, and a compact[1] than a loose one. Moreover, a clay is not one chemical compound, but an intimate mechanical mixture of several minerals. The more impurities a clay contains (quartz, feldspar, mica, etc.), the more liable will these be to combine upon heating to a fusible compound and attack the practically infusible clay substance (kaolinite). The result of the chemical analysis will therefore be the more applicable the purer the clay, but in any case will only have an approximate value, and must be supplemented by actual experiment.

II. — The Experimental Method.[2]

A. *Introductory.*

Experimental methods may be classified as direct and indirect. Until lately all the direct methods have given only what may be called qualitative results, *i.e.*, small samples of clay have been exposed to an elevated temperature and the effect has been noted, whether as a complete fusion or only as a fritting, or whether the clay remains unaltered. Examples of this method are the tests of Knafft, Bischof, and Otto. Knafft[3] exposes the end of a small pointed cone of clay for a short time to the hottest part of the flame of a blowpipe with the result that the point remains unaltered or becomes rounded off or fused. Bischof prefers to expose the clay to the flame in the loop of a platinum wire. He obtains it in a suitable form by coating a piece of oiled paper with a thin paste of the clay and water and then drying, when the clay peels off in small thin tablets. Another of his qualitative tests[4] is to place a small sample of dry pulverulent clay in a crucible and heat it in a furnace with forced draught for two hours

[1] Bischof, Thonindustrie-Zeitung 1886, p. 430; Seger, ibid., 1890, p. 201.
[2] Bischof, op. cit., p. 92; Kerl, op. cit., p. 62; Post, op. cit., p. 50.
[3] Dinglers Polyt. Jour., Vol. CLXXIV, p. 292.
[4] Op. cit., p. 93.

or more. The clay will remain unchanged, or will be fritted or fused according to the degree of refractoriness. His effective tests to distinguish fritting from fusing are to draw a line with pen and ink over the fracture of the sample or touch it with the tongue. If it is fritted it will adhere, and the ink will spread as it would on blotting-paper; if it is fused it will not stick to the tongue, and the pen and ink line will be sharp and clear. The transition from qualitative to quantitative work is made by Otto,[1] who forms two small test-bricks ($4\frac{3}{4}$ by $2\frac{3}{4}$ by $1\frac{3}{4}$ inches) from a uniform mixture of half-raw and half-burnt clay, places them alternately with two other bricks of the same size and of known properties to form an oblong on a refractory pedestal in a crucible furnace, and then heats them with charcoal, coke, and forced draught for about two hours. A comparison of the four samples shows if the heat was uniform, and how the test bricks compare with the standards. The only quantitative direct method is that by Seger and Cramer,[2] who form from the sample of clay to be tested a number of cones of the same size as Seger's small-sized standard cones, Nos. 26 to 36, inclose a test-cone with two different numbers of the standard cones in a magnesia crucible, and heat with gas-carbon in a Deville furnace lined with chromite. This is repeated with fresh cones and different temperatures until the place of the test-cone in the series of standards has been found. It is proposed to make at an early date an extended series of tests by this method, and further discussion of it will therefore be postponed for the present.

The indirect methods all have the common characteristic of mixing the clay that is to be tested with fluxing or refractory substances until it shows the same behavior in the fire as a given standard clay. The amount of ingredient required to accomplish this will be the measure of the fire-resisting value. All the tests so far have been made in clay crucibles, placed in a Sefström or Deville furnace, the fuel used being coke, or, preferably, gas-carbon, and the temperatures aimed at varying from 1500° to 1775° C. Bischof, who originated these methods, first used the one known as the quartz method,[3] in which he toned down refractory clays by the use of finely pulverized quartz or chemically pure silica. The manner in which silica acts on alumina and clay (kaolin) has been shown in Figure 1. Bischof was followed by Rich-

[1] Dinglers Polyt. Jour., Vol. CLXIII, p. 193; Thonindustrie-Zeitung, 1888, p. 163.
[2] Thonindustrie-Zeitung, 1891, pp. 195; 1892, pp. 675, 747; 1893, p. 339.
[3] Dinglers Polyt. Jour., Vol. CLIX, p. 54; Vol. CLXI, pp. 208, 291.

ters, who devised the supplementary alumina method,[1] which tones up a low-grade clay with pure alumina until it shows the same behavior in the fire as the standard, together with which it is heated. The disadvantages of these methods, namely, the excessive nicety required in regulating the high temperatures with the silica method, and the tendency of the reagent in the alumina method to act too powerfully, and also the fact that the silica method is not always applicable, prompted Bischof to combine the two in his silica-alumina method,[2] in which he uses as ingredient an intimate mixture of equal parts of chemically pure silica and alumina. This does not soften at the highest temperatures, and as it is more refractory than the best clay known, it will always tone up any clay to which it is added. The mode of procedure is to weigh out ten samples of 0.1 gramme each of clay that has been ground and ignited, to mix them severally with 0.1, 0.2, 0.3, etc., grammes of the ingredient, and form prisms $\frac{1}{4}$ inch high and $\frac{5}{32}$ inch square. These are inclosed in crucibles ($1\frac{3}{4}$ inches high, $1\frac{1}{2}$ inches in diameter at the top and $\frac{3}{4}$ inch at the base, with walls $\frac{3}{16}$ inch in thickness), three or four in each, with a prism of the standard consisting of equal parts of Saarau clay (see Table I), and the ingredient, and the value of which is assumed as 100. The crucibles are placed in a Deville furnace and heated to the melting point of wrought iron (say 1600° C.). The prism, which shows the same behavior in the fire as the standard, is the critical mixture. An arithmetical expression for the refractoriness is obtained by multiplying the amount of ingredient it contains by 100, and deducting the product from the value of the standard. Thus, if 0.1 gramme test-clay required 0.5 grammes of ingredient, its refractory value would be:

$$100 - 0.5 \times 100 = 50.$$

In this manner the relative refractoriness of the seven standard clays in Table I was determined by Bischof.

B. *New Experiments.*

1. *Introductory.* — Hitherto experiments with fire-clays have always been carried on in crucibles and with extremely high temperatures. The sample has necessarily been excluded from view during the opera-

[1] Ibid., Vol. CXCI, pp. 59, 150, 229; Vol. CXCVII, p. 268.

[2] Dinglers Polyt. Jour., Vol. CXCVI, pp. 438, 525; Vol. CXCVIII, p. 396.

Fig. 2.
SIDE ELEVATION

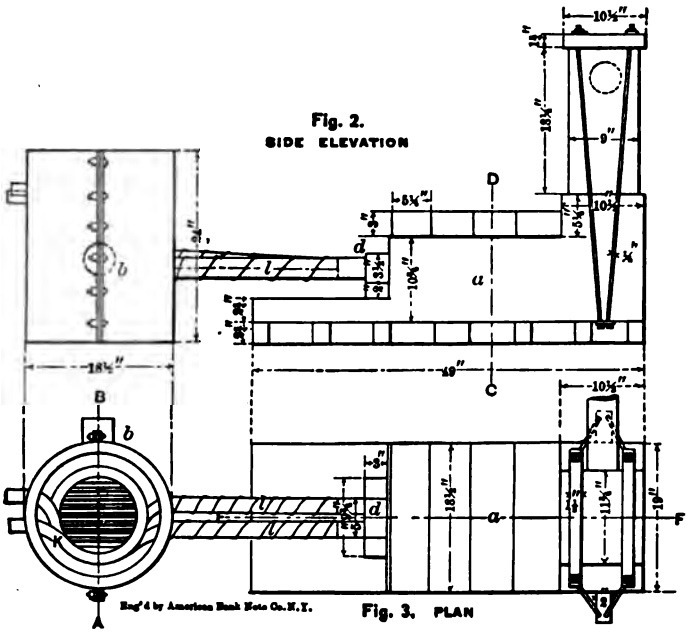


Fig. 3. PLAN

Fig. 4.
SECTION ON A. B.

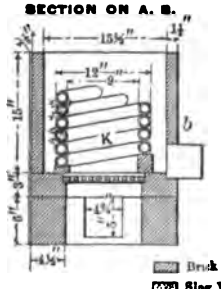


Fig. 6.
SECTION ON E. F.

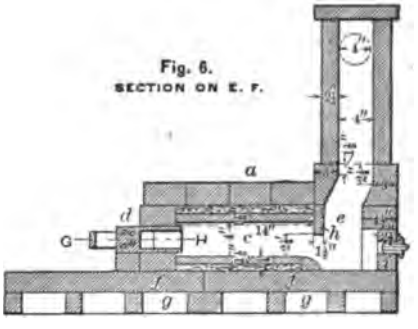


Fig. 5.
SECTION ON C. D.

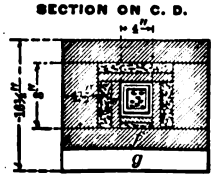
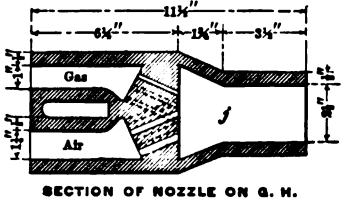


Fig. 7.



SECTION OF NOZZLE ON G. H.

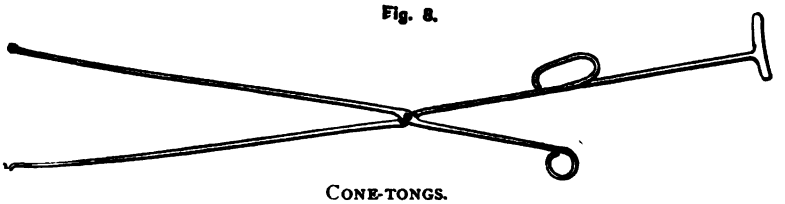
tion, and the changes could only be observed after the crucible had been taken from the fire and sufficiently cooled to allow an examination of its contents. The temperature of a small crucible-furnace using solid fuel and blast could not be controlled with any degree of nicety, and the measurement of changes of temperature in the crucible, if not impossible, was at least not satisfactory. The writers have therefore attempted:

(*a*) To construct a furnace in which the temperatures could be easily measured and controlled, and the samples watched while the tests were being made, and taken out or exchanged with little or no delay.

(*b*) To devise a method of testing which did not require temperatures approximating to or surpassing the melting point of platinum, or 1775° C.

2. *The Furnace.* — Figures 2 to 7 represent the form of furnace finally adopted after a series of preliminary experiments. In it all the

Fig. 8.



CONE-TONGS.

work here to be described was carried out. It consists of two parts, the furnace proper, *a*, and the heating stove, *b*. The furnace is built on the same principle as the one used by Dr. W. W. Jacques, physicist of the Bell Telephone Company for high temperature work. It consists of a rectangular combustion chamber, *c*, having a nozzle, *d*, at one end for the supply of gas and air, and a well-braced vertical chimney, *e*, at the other to carry off the products of combustion. The chamber is inclosed with thin fire-bricks (Figures 5 and 6), which are surrounded by slag-wool to reduce the loss of heat by radiation. It rests on two tiles; the side walls are of ordinary fire-brick laid in clay, and the roof is of four tiles laid dry. At the flue-end of the chamber there is a curtain-brick, *h*, which deflects the flame away from the roof, and thus produces a more uniform temperature than would otherwise be possible.[1] At the foot of the chimney is the working-door, $4\frac{1}{2}$ by

[1] This might perhaps be done in a simpler way by drawing the products of combustion downward instead of upward.

5 inches, through which the samples of clay to be tested are introduced with a long pair of tongs (Figure 8, one arm 45 inches, the other 34 inches), which have proved very serviceable. The working-door is closed with a fire-brick, *i*, having a peep-hole in the center, through which a pyrometer can be inserted. It is usually closed with a clay plug. The nozzle, *d*, drawn to a larger scale in Figure 7, is so constructed that gas and air coming into the chamber, *j*, obliquely to one another in a number of small streams are intimately mixed before they issue forth into the furnace, and this insures a very satisfactory combustion. The chamber soon becomes dazzling white. To enable the nozzle to resist this intense heat, it is made of suitable proportions of raw and burnt clay, alumina and asbestos; it is air-dried for several weeks and then placed in the furnace without previous baking. The stove (*b*, Figures 2, 3, etc.), in which air and gas are heated before they come together in the nozzle, was proposed by Prof. R. H. Richards. It consists of a sheet-iron cylinder lined with fire-clay and closed at the top with a sheet-iron cover ($\frac{1}{8}$ inch thick, not shown in the drawing) having two peep-holes. Above the ash pits is a circular cast-iron grate on which rest the two heating-coils, *k*, made of wrought-iron pipe wound together. The hot gases from the charcoal fire maintained on the grate pass up inside the coils, down on the outside, and then off through the flue, which is at the level of the grate. Thus the coils are heated outside as well as inside. Two pieces of wrought-iron pipe, *l*, inclosed in slag-wool, which is held in place by asbestos-paper and wire, are screwed on to the protruding ends of the heating coils; they abut against the clay nozzles, the joints being made air-tight with a luting of clay and slag-wool. This furnace, like every other, shows a difference of temperature between the places where the flame enters and those where it leaves the chamber. The first step was to settle the distances from the nozzle within which the temperature was uniform. The observations made with the Le Chatelier pyrometer are given in Table II. They show a uniform temperature in the space between $4\frac{1}{2}$ and 10 inches from the nozzle. These measurements were made along the bottom of the furnace, when it was 4 inches wide and 6 inches high, and the layer of slag-wool on the bottom and the deflecting curtain had not yet been added. Hence the roof of the furnace showed at that time a higher temperature than the floor. The highest temperature attained in the furnace was 1720° C., at about 3 inches from the floor and $4\frac{1}{2}$ inches from the

nozzle. A still higher temperature was expected, as in a larger furnace of similar construction, not having any provision for reducing the loss of heat by radiation, platinum had been melted in two hours after starting, the gas entering the heater through a $\frac{5}{8}$-inch pipe connected directly with a 3-inch main. The reason for the failure is the lack of gas, for, although a $\frac{5}{8}$-inch pipe is used, it passes through long and tortuous passages to reach the main. The temperatures attained were, however, more than sufficient for the tests.

TABLE II. — MEASUREMENTS OF TEMPERATURE IN FURNACE.

Distance from Nozzle. Inches.	Degrees centigrade.			
$1\frac{1}{2}$	1280	1395	....	....
$4\frac{1}{2}$	....	1420	....	....
$5\frac{1}{2}$	....	....	1360	1420
$7\frac{1}{2}$	1280	1430	....	....
$8\frac{1}{2}$	....	....	1370	1425
$10\frac{1}{2}$	1335	1420	....	....
$11\frac{1}{2}$	....	....	1355	1390
$13\frac{1}{2}$	1330	1345	....	....
$14\frac{1}{2}$	....	....	1210	1230

3. *The Standard of Measurement.* — Before entering upon the experiments proper, it was necessary to settle upon the standard by which any results were to be measured. Bischof's standard clays could not be taken, as the character of the deposits from which he received his material has changed, and samples of the old clays are not in the market. To overcome this difficulty, Seger got up his three-sided pyramids, going by the name of "Seger Cones." They are made with varying proportions of feldspar, kaolin, alumina, marble, quartz, and ferric oxide. The first set,[1] $\frac{3}{4}$ inch at base and $2\frac{3}{8}$ inches in height, contains twenty pieces, the respective numbers, Nos. 1 to 20, being impressed on them. They are intended to measure temperatures varying from 1150° C. to 1700° C., the difference between each cone

[1] Thonindustrie-Zeitung, 1886, pp. 135, 145, 168, 229.

and its neighbor being calculated as 28.9° C. The temperature indicated by the cone is supposed to be reached when its apex has bent down to the base.

Figure 9 presents a series of five cones, four of which illustrate the different stages of fusion, while the fifth (the largest, which has not been in the fire) shows how considerable is the shrinkage that takes place upon heating. A second set of cones of the same size, Nos. 21 to 25, and a third one of smaller proportions, Nos. 26 to 36,[1] melting at a gradually increasing temperature, No. 36 having the composition Al_2O_8, 2 SiO_2, complete the row in the ascending temperature scale. Last year a new set of ten cones of the large size was

brought out by Cramer.[2] They are marked 010, 09, ... 01, 1, and are intended to measure temperatures ranging from 960° C. to 1150° C., the difference of temperature indicated by each interval being 19° C. All these cones are to be obtained at about one cent apiece from the Royal Prussian Porcelain Manufactory of Berlin, so well known to chemists. It was at first our intention to use the high numbers of the large-sized Seger cones as standards. On melting down several of them, measuring the temperatures at the same time with the Le Chatelier pyrometer, it was found that the fusions were completed at temperatures much lower than called for by the numbers of the cones. It did not lie within the province of the work contem-

[1] Thonindustrie-Zeitung, 1886, pp. 135, 145, 168, 229; 1888, pp. 152, 162.
[2] Ibid, 1892, p. 155.

plated to measure accurately the melting-points[1] of these cones; so it was decided to adopt the Le Chatelier pyrometer, against the results of which no objection has ever been raised. This pyrometer has been repeatedly described.[2] The small change required to adapt the instrument to the furnace consisted in fastening the clay cylinders ($\frac{3}{8}$ inch in diameter), through which the thermal wires pass, with platinum wires to an electric-light carbon instead of inserting them in the iron pipe commonly used, as this could not be safely subjected to the temperature of the furnace, and, moreover, would have absorbed too much heat. The change was not wholly satisfactory, because the carbon burns off and leaves the binding of the wire loose. A better arrangement is to choose small-sized clay cylinders ($\frac{3}{16}$ inch in diameter) for the thermal wires, and inclose them in a thin clay tube, which can stand sudden changes of temperature.

The form adopted for the test-pieces was that of the large-sized Seger cone. As the cones are not absolutely uniform in size, the dimensions $\frac{3}{4}$ by $\frac{3}{4}$ by $\frac{7}{8}$ inch for base and $2\frac{3}{8}$ inches for the sides were selected, after measuring a number of the originals, as being the best average. It will be noted that the dimensions differ somewhat from those usually quoted, and given on a preceding page.

The clay and other substances used in the experiments were all decidedly finer than what would pass through a 100-mesh sieve. They were first mixed dry, either by hand or mechanically in a Morrell agate mortar, then moistened on a glass plate with just enough water to render them plastic, and then worked with the spatula. To the water 5 per cent. of dextrine was added, when it was found necessary to give the cone additional firmness. The mould used (Figures 10 and 11) consists of three blocks of oiled wood held together by two 3-inch clamps. In making the cones two parts, A and B, of the mould are clamped together, the clay-mixture is pressed in with the spatula, the third part, C, is clamped on; the clay is pressed in firmly from the open base with a suitable piece of wood to insure a good edge and a sharp point, and the mould is then carefully taken apart. The samples were air-dried

[1] For the discussion, see *pro:* Thonindustrie-Zeitung, 1887, pp. 43, 84, 125, 197, Seger; p. 2, Heintz; pp. 52, 81, Hülsmann; p. 185, Hecht; and *con:* Thonindustrie-Zeitung, 1887, pp. 43, 87, Bischof; 1888, p. 61, Jochum.

[2] Le Chatelier, Journal de Physique, 2d series, VI, January, 1887; Génie Civil, March 5, 1887; Howe, Eng. and Min. Jour., October 11, 1890; Struthers, School of Mines Quarterly, XII, 143, and XIII, 221; Berg. und Hütten. Zeitung, 1892, 277, 301, 310; and Roberts-Austen, "Recent Advances in Pyrometry," Trans. Am. Instit. Mining Engineers, Vol. XXIII.

from fifteen to twenty hours, then slowly heated on an iron plate over a Bunsen burner and placed in the furnace near the flue, where they remained until red-hot, when they were transferred to their position

Fig. 10.

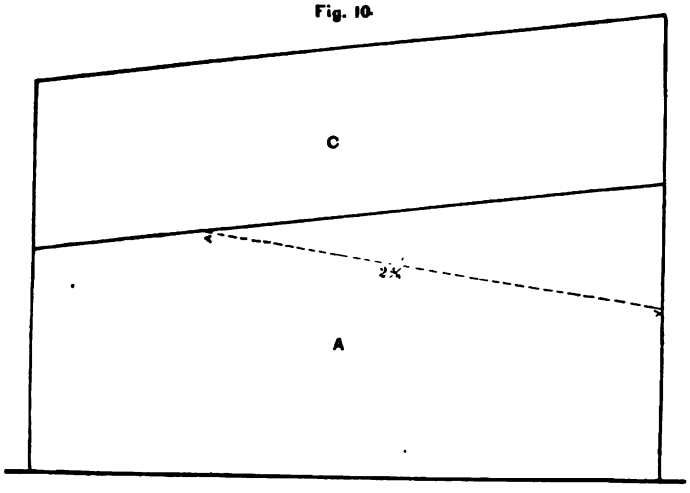
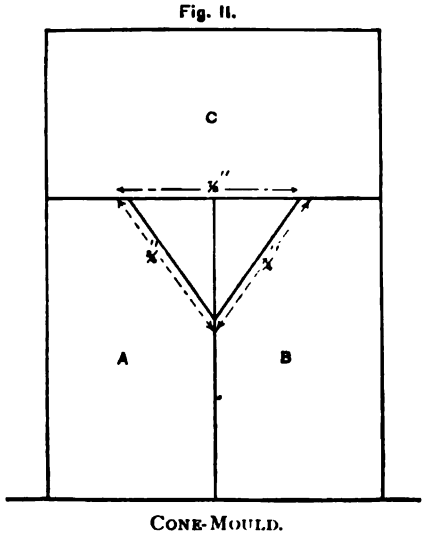


Fig. 11.



CONE-MOULD.

4½ inches from the nozzle, where the flame would play squarely upon them. To prevent their sticking to the bottom, it was covered with a thin layer of Mt. Savage clay. The criterion of fusion was the same

as that of the Seger cone, but when a sample bent over so that it was wholly below the flame, it was considered to have been fused, though the apex might not quite touch the base. After each experiment and the subsequent measuring of the temperature, the furnace was somewhat cooled down by shutting off the gas. The air was still allowed to pass through for a few minutes, and was then shut off, while the samples were taken out and replaced by new ones, when the air was turned on again and followed by the gas, the amounts of both being quickly increased to the desired degree. The proportions were so regulated that the flame should be slightly smoky.

4. *The Method.* — The method followed is based on the use of calcium carbonate as a flux. The amount of lime it is necessary to add to a weighed quantity of clay to form a fusible compound at a certain elevated temperature will form the criterion of the refractory value of the clay. Åkerman[1] has shown how the fusibility of silicate of lime is increased by successive additions of alumina. Cramer[2] got up, in 1887, a series of cones composed of Zettlitz kaolin and increasing proportions of marble to take the place of Bischof's standard clays. While Seger[3] highly approved of the series as far as the different degrees of fusibility were concerned, he made the objection that the mixtures melted down suddenly at the critical temperatures, while the melting down of clay is slower and more gradual. The writers' experiments show that this sudden collapse of a cone takes place only with very fusible mixtures (*e.g.*, cone No. 5), and that with refractory mixtures the bending over of a cone takes place in a way that is very similar to that of Seger's own cones. As lime is a very powerful flux, and would, therefore, have a strong effect if added, even in small proportions, to a fire-clay, it seemed advisable to try and weaken this effect by diluting with silica and using the mixture instead of the stronger pure calcium carbonate. Experiments of this character were carried on with clay from Mount Savage, Maryland, and with kaolin from Blanford, Massachusetts. A third set of experiments was made with a common brick-clay from Cambridge, Massachusetts. The method here followed was that of Bischof (see page 9) of toning up a clay with alumina, the strength of which has been weakened by silica.

[1] Stahl und Eisen, 1886, pp. 281 and 387; abstracted in Jour. I. and S. Inst., 1886, p. 310.

[2] Thonindustrie-Zeitung, 1887, p. 197; see also Bischof, Thonindustrie-Zeitung, 1888, pp. 38 and 50.

[3] Ibid, 1888, p. 153.

Table III gives the composition of the materials used in the experiments.

5. *Experiments with Fire-clay from Mount Savage, Maryland.* — The clay experimented upon belongs to the hard variety;[1] it has a conchoidal fracture; its color varies from light gray to dark chocolate brown; it disintegrates very slowly when exposed to the air and is plastic only when ground very fine. It is infusible before the blowpipe.

The results of the experiments with the light variety are brought together in Table IV and illustrated by Figure 12.

Experiments Nos. 1 to 4, in which pure calcium carbonate was added to the clay, form a good series, for the fusibility increases regularly with the additions of the flux. Cones Nos. 1 and 2 are quite fused, No. 3 is just fused, while No. 4 is only glazed and not bent over. The critical mixture contains, however, only between 5 and 10 per cent. of the flux, which is a very small quantity of reagent to produce such a decided result.

Experiments Nos. 5 to 8, where equal parts of silica and calcium carbonate are used, show little improvement over those with calcium carbonate alone. That cone No. 5 should have melted as soon as full gas had been turned on was to be expected from its low refractory quotient. It is the only example of the sudden fusion of the clay-lime mixture objected to by Seger that occurred in the experiments. The critical mixture contains from 10 to 20 per cent. of the flux. The temperatures are lower than might have been expected from the refractory quotient.

Experiments Nos. 9 to 11, with silica to calcium carbonate as 3 to 1, make a decidedly better showing than those with silica and calcium carbonate in equal parts. The critical mixture contains between 20 and 30 per cent. flux, and while the temperatures are higher than before, viz., 1510° C. *vs.* 1440° C., the difference is not great enough to invalidate the comparison.

Experiments Nos. 12 to 15 represent the mixtures of clay with the flux, five silica to one calcium carbonate, which is a further step in advance. Cone No. 12 shows good fusion; No. 13 is less completely bent; No. 14 is just a little inclined; and No. 15 is only glazed and beaded at the apex. The critical mixture contains from 30 to 40 per cent. of flux.

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[1] See R. A. Cook, Trans. Am. Instit. Mining Engineers, Vol. XIV, p. 698.

TABLE III.—ANALYSES OF MATERIALS.

Name of Material.	Al_2O_3.		SiO_2.				RO.							Loss by ignition.	O in Al_2O_3. ÷ 3O in RO.	O in SiO_2. ÷ 3O in RO.	O in SiO_2. ÷ O in Al_2O_3.	Refractory Quotient.	
	Total per cent.	Oxygen, per cent.	Combined per cent.	Non-combined per cent.	Total per cent.	Oxygen, per cent.	MgO per cent.	CaO per cent.	Na_2O per cent.	K_2O per cent.	Fe_2O_3 per cent.	Total per cent.	Oxygen, per cent.					Bischof R. Q. B.	Seger R. Q. S.
Fire-clay, Mt. Savage, Maryland.[1]	29.10	13.56	28.35	31.84	60.19	32.08	trace.	....	0.	03	0.89	0.92	0.18	9.90	25.11	59.41	2.36	10.64	35.81
Kaolin, Blanford, Mass.[2]	31.76	14.80	.....	.....	52.03	27.73	0.54	trace.	trace.	trace.	trace.	0.54	0.22	15.55	22.42	42.01	1.87	11.99	34.45
Brick-clay, Cambridge, Mass.[3]	28.90	13.46	18.04	30.95	48.99	26.11	3.66	7.10	4.73[4]	Cl0.13 SO 3 0 20	4.32	19.81	5.57	2.98	0.80	1.56	1.93	0.41	1.22
Quartz, Berkshire, Mass.	.....	.....	.....	.....	99.88	53.24	....	....	....	....	0.12[5]	0.12	0.02	....	.....	.....	.....	.....	.....
Alumina, Syracuse, N. Y.[6]	98.46	45.88	.....	.....	0.25	0.13	....	....	0.50[7]	....	0.04	0.54	0.13	0.75	.....	.....	.....	.....	.....
Calcium carbonate . .	.....	.....	.....	.....	.. ..	....	....	56	....	....	....	.....	.....	44	.....	.....	.....	.....	.....

[1] Kimmicut and Rogers, Journal of Analytical and Applied Chemistry, Vol. V, p. 542; Eng. and Mining Journal, December 12, 1891.
[2] Norton, Technology Quarterly, Vol. III, p. 231.
[3] Card — Thesis in Geological Department, Massachusetts Institute Technology, 1892.
[4] Equivalent to 7.17 K_2O.
[5] Assumed; previous analysis having shown the main impurity to be iron.
[6] Solvay Process Co.
[7] Equivalent to 0.75 K_2O.

TABLE IV.—EXPERIMENTS WITH FIRE-CLAY FROM MOUNT SAVAGE, MARYLAND.

Number of Experiment and Cone.	Components of Mixture.			Composition of Mixture.						Refractory Quotient.		Temperature, °C.	Remarks.
	Clay, per cent.	Quartz, per cent.	Calcium carbonate, per cent.	Al_2O_3 per cent.	O per cent.	SiO_2 per cent.	O per cent.	RO per cent.	O per cent.	Bischof R. Q. B.	Seger R. Q. B.		
.....	100	.....	.....	29.10	13.56	60.19	32.08	9.92	0.18	10.64	35.81	.....	Added for the sake of comparison.
1	80	.....	20	23.28	10.85	48.15	25.66	11.94	3.34	0.45	1.54	1470	Were together in the furnace, and were removed together. No. 1 fused before No. 2.
2	85	.....	15	24.73	11.53	51.16	27.26	9.18	2.55	0.63	2.14	1470	
3	90	.....	10	26.19	12.20	54.17	28.87	6.43	1.76	0.97	3.28	1580	Were together in the furnace, and were removed together. No. 3 fused; No. 4 only superficially glazed.
4	95	.....	5	27.65	12.88	57.18	30.47	3.67	0.97	1.87	6.30	1580	
5	40	30	30	11.64	5.42	54.04	28.80	17.20	4.88	0.07	0.43	.....	Melted at once when full gas was admitted.
6	60	20	20	17.46	8.13	56.09	29.89	11.77	3.31	0.22	1.04	1340	Melted quickly.
7	80	10	10	23.28	10.85	58.14	30.99	6.35	1.75	0.72	2.78	1440	Were together in the furnace; No. 7 fused slowly; No 8 but slightly glazed.
8	90	5	5	26.19	12.20	59.16	31.53	3.63	0.96	1.63	5.10	1440	

TABLE IV. — EXPERIMENTS WITH FIRE-CLAY, FROM MOUNT SAVAGE, MARYLAND. — *Concluded.*

Number of Experiment and Cone.	Components of Mixture.			Composition of Mixture.						Refractory Quotient.		Temperature, °C.	Remarks.
	Clay, per cent.	Quartz, per cent.	Calcium, carbonate per cent.	Al_2O_3 per cent.	O per cent.	SiO_2 per cent.	O per cent.	RO per cent.	O per cent.	Bischof R. Q. B.	Seger R. Q. B.		
9	60	30	10	17.46	8.13	66.07	35.22	6 19	1.71	0.36	1.95	1420	Fused slowly.
10	70	22.5	7.5	20.37	9.49	64.61	34.43	4.87	1.33	0.65	3.02	1510	Were together in the furnace. No. 10 fused slowly; No. 11 is glazed and has a rounded point.
11	80	15	5	23 80	10.85	63.13	33.65	2.85	0 81	1.44	5.90	1510	
12	40	50	10	11 64	5.42	74.02	39.45	6.03	1.68	0.14	1.22	1470	Together in furnace; temperatures are averages of two series of experiments; both fused slowly; No. 12 is seen to be more fused than No. 13.
13	50	41.7	8.3	14.55	6.78	71.74	38 24	4.74	1.34	0.29	1.98	1470	
14	60	33.3	6.7	17.46	8.13	69.37	36.97	4.34	1.18	0.50	2.80	1600	Together in furnace; No. 14 somewhat fused; No. 15 glazed and beaded at apex.
15	70	25	5	20.37	9.49	67.10	35.76	3.47	0.93	0.90	4.30	1600	

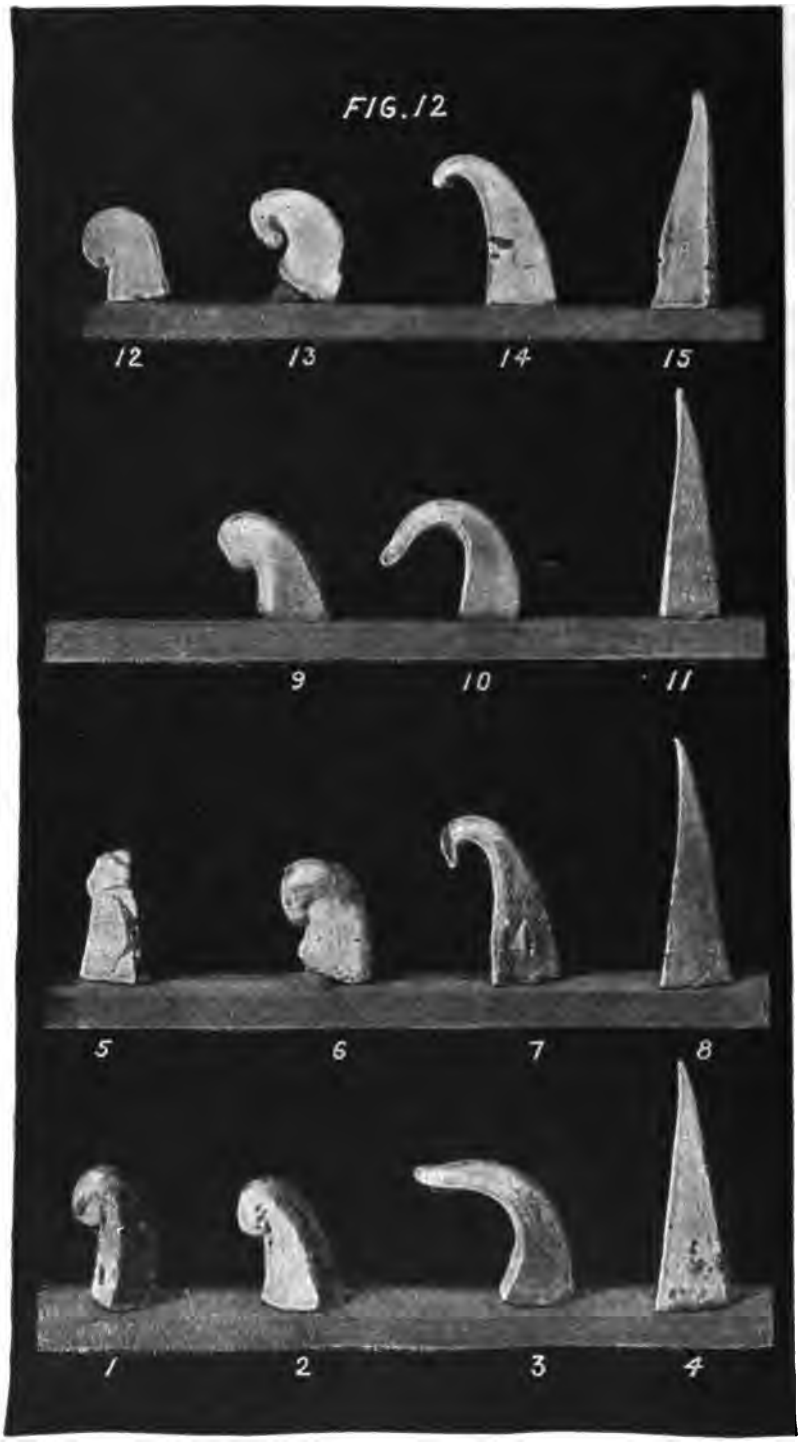
FIG. 12
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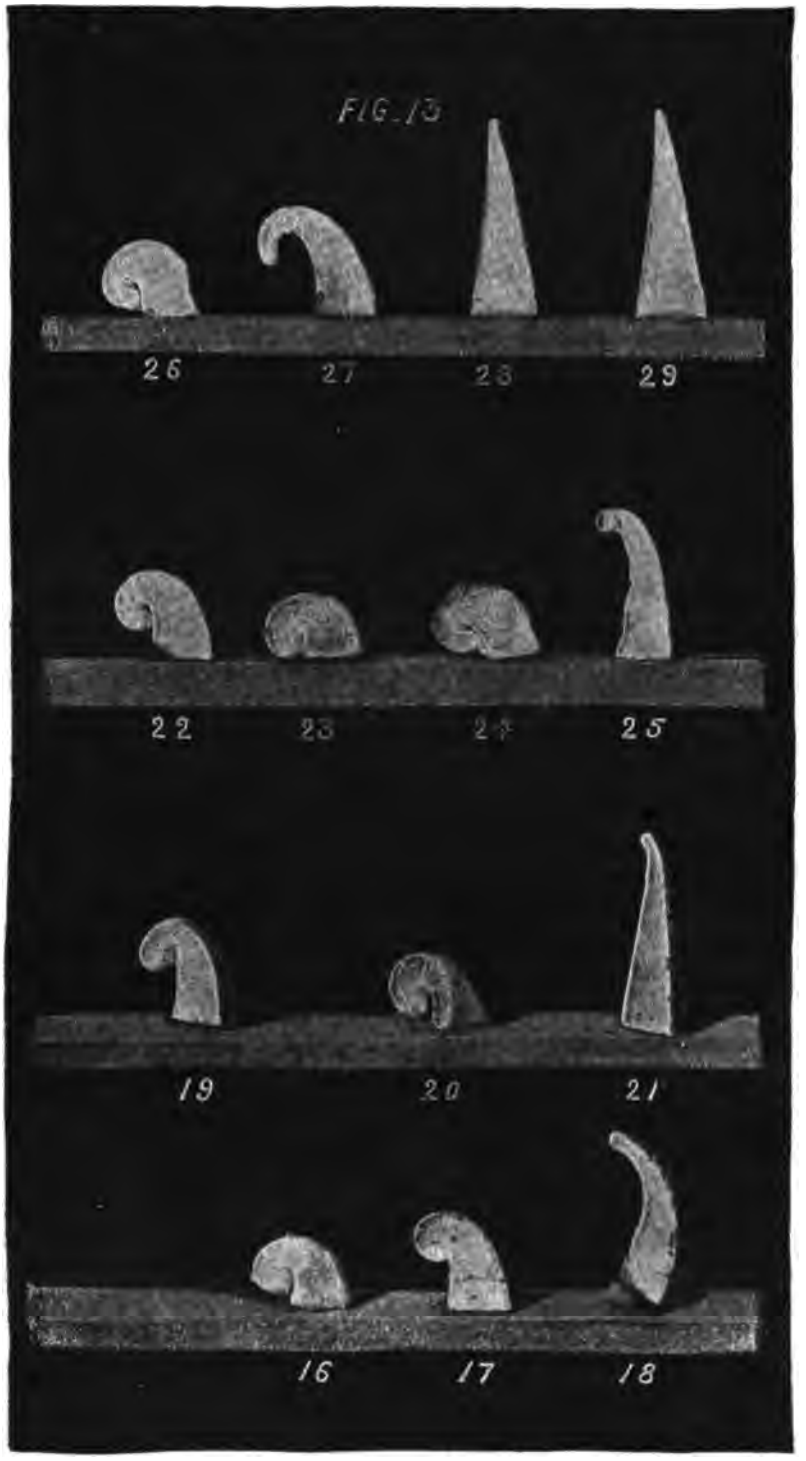
FIG. 13
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The proportion of five silica to one calcium carbonate is the highest that was used. A mixture still richer in silica than this might possibly be better for fire-clays less refractory than that from Mount Savage; but five silica to one calcium carbonate is sufficient so long as the mixture fulfills the necessary condition of being weak enough to be used in considerable quantities without having too great an effect. This is important, as there must be difference enough in the amounts added to the various clays to afford a satisfactory scale for measuring their fusibility.

6. *Experiments with kaolin from Blanford, Massachusetts.* — The kaolin from Blanford, Massachusetts,[1] used in these experiments is soft, pinkish white, and slightly plastic. It has a high degree of purity, as seen by the analysis (Table III), and is infusible before the blowpipe. The sample received, weighing about twelve pounds, was a mixture of friable kaolin and more or less disintegrated crystals of mica and quartz. As it was desired to have the purest kaolin obtainable, the original sample was dried and worked without grinding through a series of screens to remove the mica and quartz, that only which had passed through a 100-mesh sieve (25 per cent. of the original amount) being reserved for the experiment after it had received a final grinding in a Morrell agate mortar.

The experiments Nos. 16 to 29 were carried on in the same manner as those with the clay from Mount Savage. The results obtained are brought together in Table V, and the cones are represented by Figure 13. If they are compared with those obtained with Mount Savage clay it will be seen, first, that the critical mixtures in the corresponding cases contained the same amount of flux, and secondly, that those having a higher refractory quotient require also a higher temperature. An exception to this is found with the flux containing five silica and one calcium carbonate where cones Nos. 26 to 29, with a large refractory quotient, show lower temperatures than cones Nos. 12 to 15 with a small one. The explanation is wanting.

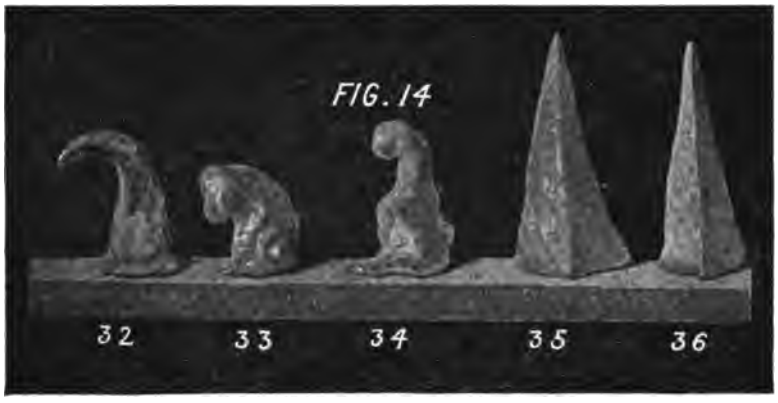
7. *Experiments with Brick-Clay from Cambridge, Massachusetts.* — This clay is largely used in the brickyards of Cambridge. It is soft, light gray, and plastic, shows a considerable number of impurities, and is readily fusible. It was chosen to test in the new furnace Bischof's method of toning up a low grade clay with a mixture of equal parts

[1] Crosby, Technology Quarterly, Vol. iii, p. 228.

of silica and alumina, so it shall fuse only at an elevated temperature. The experiments are recorded in Table VI, and of the cones obtained, Nos. 30 to 36, only Nos. 32 to 36 are shown in Figure 14.

Experiments Nos. 30 and 31 show how readily fusible the clay is; in fact, the specimens, upon heating, quickly swelled up into a spongy mass; even with 20 per cent. of stiffening ingredient, fusion occurred at 1,300° C., and it required from 40 to 50 per cent. of the ingredient to enable the clay to resist a high temperature.

8. *Conclusion.* — In the foregoing experiments a definite standard temperature has not been sought. It seemed of greater importance to study first the behavior of several series of mixtures of clay, silica, and lime at elevated temperatures, and to measure these. Of the



fluxes tested, the mixtures of three silica to one calcium carbonate and five silica to one calcium carbonate have proved valuable; and further series of tests with a number of analyzed refractory clays will be needed to decide whether the proportion of five silica to one calcium carbonate, which has so far proved the better of the two, can maintain its position or will have to yield to a mixture that is more siliceous. In these final experiments it will be necessary to maintain a definite temperature (which is easily done with the furnace) and make it the standard. Experience so far seems to show that 1,500° C. is the best. It is also proposed to make a parallel series of tests by Seger's direct method, and compare the results with those from the indirect silica-lime method.

TABLE V.—EXPERIMENTS WITH KAOLIN FROM BLANFORD, MASSACHUSETTS.

Number of Experiment and Cone.	Components of Mixture.			Composition of Mixture.						Refractory Quotient.		Temperature, °C.	Remarks.
	Kaolin, per cent.	Quartz, per cent.	Calcium carbonate, per cent.	Al_2O_3 per cent.	O per cent.	SiO_2 per cent.	O per cent.	RO per cent.	O per cent.	Bischof R. Q. B.	Seger R. Q. S.		
.....	100	.....	.....	31.76	14.80	52.03	27.73	0.54	0.22	11.99	34.45	.....	Added for sake of comparison.
16	85	.....	15	26.99	12.58	44.22	23 57	8.86	2.58	0.86	2.49	1490	Were together in furnace. No. 16 well fused; No. 17 less so.
17	90	.....	10	28.58	13.32	46.83	24.96	6.09	1.79	1.32	3.80	1490	
18	95	.....	5	30.17	14.06	49.43	26.34	3 31	1.00	2.50	7.18	1640	Only well bent.
19	70	15	15	22.23	10.36	51.40	27.39	8.79	2.56	0.51	1.85	1370	Fused.
20	80	10	10	25.41	11 84	51.61	27.51	6.04	1.77	0.96	3.18	1490	Fused.
21	90	5	5	28.58	13.32	51.82	27.62	3.29	1.00	2.14	6.58	1610	Only beaded at the apex.
22	50	37.5	12.5	15.88	7.40	63 47	33.83	7.31	2.12	0.25	1.45	1330	Fused.

TABLE V.—EXPERIMENTS WITH KAOLIN FROM BLANFORD, MASSACHUSETTS.—*Concluded.*

Number of Experiment and Cone.	Components of Mixture.			Composition of Mixture.						Refractory Quotient.		Temperature, °C.	Remarks.
	Kaolin, per cent.	Quartz, per cent.	Calcium carbonate, per cent.	Al_2O_3 per cent.	O per cent.	SiO_2 per cent.	O per cent.	RO per cent.	O per cent.	Bischof R. Q. B.	Seger, R. Q. S.		
23	60	30	10	19.06	8 88	61.18	32.61	5.96	1.74	0.46	2 16	1500	Fused.
24	70	22.5	7.5	22.23	10.36	58.89	31.39	4.60	1.36	0.83	3.37	1560	Fused.
25	80	15	5	25.41	11.84	56 60	30.17	3.25	0.98	1.58	5.61	1660	Only well bent.
26	60	33.33	6.67	19.06	8.88	64.51	34.38	4.09	1.20	0.63	3.10	1340	Fused.
27	70	25	5	22.23	10.36	61.39	32.72	3.21	0.96	1.13	4.73	1380	Fused half down.
28	80	16.67	3.33	25.41	11.84	58.53	31.06	2.32	0.71	2.11	7.67	1580	Only slightly beaded at the apex.
29	90	8.33	1.67	28.58	13.32	55.14	29.39	1.43	0.46	4.37	14.02	1580	Unaffected.

TABLE VI.—EXPERIMENTS WITH BRICK-CLAY, FROM CAMBRIDGE, MASSACHUSETTS.

Number of Experiment and Cone.	Components of Mixture.			Composition of Mixture.						Refractory Quotient.		Temperature, °C.	Remarks.
	Brick-clay, percent.	Quartz, per cent.	Alumina, per cent.	Al_2O_3 per cent.	O per cent.	SiO_2 per cent.	O per cent.	RO per cent.	O per cent.	Bischof R. Q. B.	Seger R. Q. S.		
.....	100	.....	.....	28.90	13.46	48.99	26.11	19.81	5.57	0.41	1.22	.....	Added for the sake of comparison.
30	90	5	5	30.93	14.41	49.09	26.16	17.86	5.02	0.52	1.48	?	Fused at once when half the gas was turned on.
31	85	7.5	7.5	31.94	14.88	49.15	26.19	16.88	4.74	0.59	1.64	?	
32	80	10	10	32.96	15.35	49.20	26 22	15.91	4.47	0.67	1.81	1300	Fused.
33	70	15	15	34.99	16.30	49.31	26.28	13.96	3.92	0.86	2.24	1450	Fused.
34	60	20	20	37.03	17.25	49.42	26 34	12 02	3.37	1.11	2.82	1610	Fused.
35	50	25	25	39.06	18.17	49.53	26.39	10.23	2.85	1.46	3.58	1610	Glazed on outside but not fused.
36	40	30	30	41.09	19.15	49.66	26.47	8.12	2.27	2.14	4.95	?	Unaffected.

ON AN APPARATUS FOR THE MEASUREMENT OF CO-EFFICIENTS OF SELF-INDUCTION AND THE INVES-TIGATION OF THE PHENOMENA OF ALTERNATING CURRENTS.[1]

By FRANK A. LAWS, S.B.

Received January 11, 1894.

THE increasing use of alternating currents in telephony and electric lighting has, during the last few years, directed attention to the measurement of coefficients of self-induction. In this paper certain apparatus devised for this purpose, together with methods for its use, will be described. Further discussion of the various methods of measurement proposed and of experimental results obtained is reserved for a later article.

For investigations pertaining to telephony it is particularly desirable to measure inductances by means of alternating currents of suitable known frequencies and of the same order of magnitude as those used in practice. In all such work the reduction of the results is greatly simplified if the E. M. F. employed follows the sinusoidal law.

Therefore the aim at the outset was to produce a dynamo whose E. M. F. should vary in this manner, and whose frequency of alternation should be about that which is normal in telephonic work. Under these requirements there have been designed in the Rogers Laboratory two dynamos or arrangements of dynamos. The first of these was planned during the winter 1890–91, and was used by Mr. L. Derr in connection with his thesis in 1891–92. This machine was provided with a stationary armature having Lord Kelvin's zigzag winding on the outer surface of a hollow cylinder. This was placed in the gap between a star-shaped piece of iron and a disk with a corresponding star-shaped opening, the two pieces being similarly and concentrically

[1] Read at a meeting of the American Academy of Arts and Sciences, January 10, 1894.

placed and forming the pole pieces of the machine. Owing to the shape of the pole pieces the field between them is variable, being denser at the points of the stars, so that when the field moves past the armature an E. M. F. will be set up in the latter.

One disadvantage of this design is that the E. M. F. is small, owing to the very large non-effective field; for it is only the variation of the field that is of service in producing the electro-motive force. By properly shaping the pole pieces a curve of electro-motive force was obtained, which, when plotted, was found to be nearly sinusoidal in form.

The second machine was constructed by Messrs. C. L. Norton and P. H. Thomas, of the class of 1893, and forms the subject of the present paper. The special form of dynamo used was designed in accordance with a suggestion from them. The frequency is somewhat low, being 400 complete alternations per second. When another machine is built it will be so designed that the superior limit will be raised to 2,000 complete periods per second.

Both the machine of 1890 and that of 1892 embody the same general features. Each has two independent armatures, one fixed, the other movable in phase relation to the first. This relation is capable of measurement. At the outset it was determined that in these machines the armatures should contain no iron and that they should remain stationary, in order to eliminate any possible microphonic action at the brushes.

The machine, which is shown in place ready for use in Figure 1, will now be described. It consists, in brief, of two dynamos, with revolving fields mounted on one shaft to insure definite phase relation. The armature of one is fixed, while that of the other may be given any desired angular advance or retardation in reference to the first by means of a tangent screw. This advance can be read off from the graduated head of the screw. The fields are independent of one another. In addition to the dynamos the shaft carries a contact arrangement for mapping wave-forms, and a stroboscopic disk for determining the speed of rotation.

One of the field magnets is shown in plan in Figure 3 and in section in Figure 2. It consists of two star-shaped pieces of cast iron, keyed to the shaft and having hubs of such a length that the faces of the teeth are $\frac{5}{16}''$ apart, thus leaving a gap in which is the armature, $\frac{1}{4}''$ thick. The castings are recessed to receive the field coils,

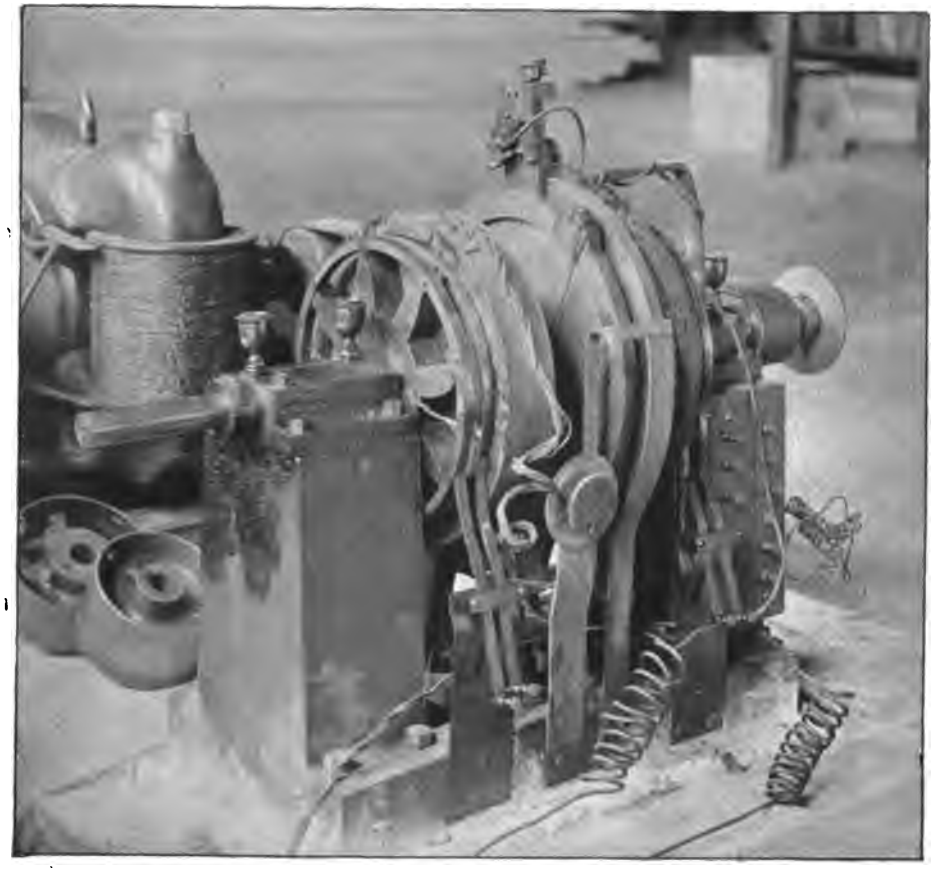


FIGURE 1.

which are about one square inch in section and contain 250 turns of No. 16 B. & S. double cotton-covered wire. The coils were wound on forms, paraffined and taped, and were inserted when the machine was

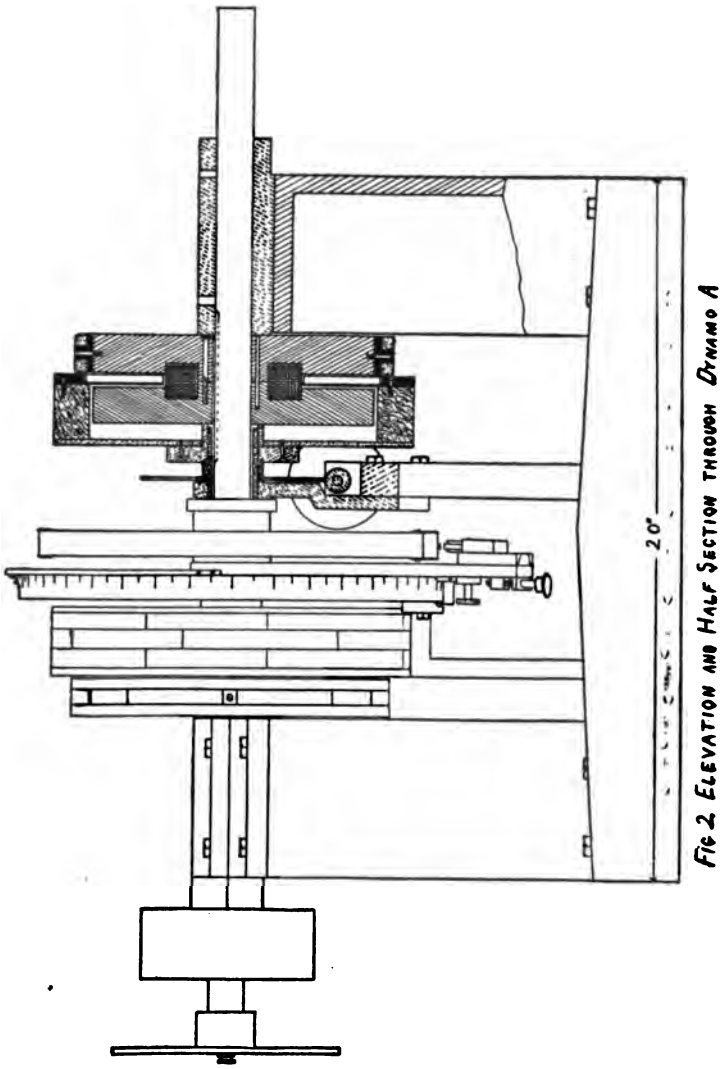


FIG 2 ELEVATION AND HALF SECTION THROUGH DYNAMO A

assembled. The terminals are brought out through bushed holes and fastened to composition collector rings which are carried and insulated by blocks of vulcanite mounted on the tips of the teeth of one of the

castings. The brushes of spring copper are supported from the base plate. The eight teeth were milled from the round by a special Brown & Sharpe cutter, and have the form of a sinusoid laid off radially from the base circle. Of course, owing to the spreading of the lines of force, the particular form to be given to the teeth in order to obtain the best action can only be obtained by trial.

The armature consists of a vulcanite disk, $10\frac{1}{4}''$ diameter, $\frac{1}{4}''$ thick, having a $4''$ hole in the middle. From this hole radiate 16 equally spaced saw-cuts $\frac{3}{16}''$ deep, $\frac{1}{16}''$ wide, and $2\frac{1}{4}''$ long, the outer extremities of alternate pairs of cuts being connected by grooves concentric with the disk. In these cuts and grooves the armature wires are laid in shellac. The windings at present consist of three sections having respectively 10, 10, 20 turns of No. 30 B. & S. copper wire. The total resistance is about 10 ohms. The manner of winding as well as the action of the dynamo, by varying the length of active wire, are evident from Figure 3. The armatures are carried by built-up hard-wood rings $10\frac{1}{4}''$ outside diameter, $8\frac{1}{4}''$ inside, and $1\frac{9}{16}''$ deep. The ring in one dynamo is attached to a brass disk and hub which fit the shaft and are rigidly bolted to the frame of the machine.

In the other dynamo, the armature, ring, disk, and hub are attached to a worm-wheel, and the whole is movable on a sleeve supported firmly from the frame of the machine. Through this sleeve passes the shaft without contact. The worm-wheel gears into a tangent screw provided with a divided head, the gearing being such that 1° on the wave form is represented by 20° on the head. Backlash is prevented by a spiral spring. See Figures 2 and 3.

Between the two dynamos is a brass disk, keyed to the shaft and provided with an insulated collector ring and contact point. By the side of this disk is a radial arm, revolving freely about the shaft and capable of being clamped at any desired point to a fixed graduated circle. The arm carries the contact spring, made of watch spring and supported on its lower side very near its extremity to prevent the lengthening of the arc of contact by vibration. The spring can be moved out of contact with the point by a fine-pitched screw. This contact arrangement we have found to work satisfactorily at as many as 3,000 revolutions per minute.

The shaft of the machine is of steel $1''$ diameter, $29''$ long, and runs in composition bearings, each of which is $5\frac{1}{2}''$ long. The frame of the machine is heavy, weighing 175 pounds, and is designed so

as to be very rigid. Driving is effected by means of a 2″ belt running over a 5″ pulley. The motor (1 H. P.) is of the Sprague type. Variations of speed are obtained by the use of pulleys of different sizes on the motor shaft.

Both machine and motor rest on a brick pier, the machine being set in sulphur; mechanically the arrangement leaves nothing to be

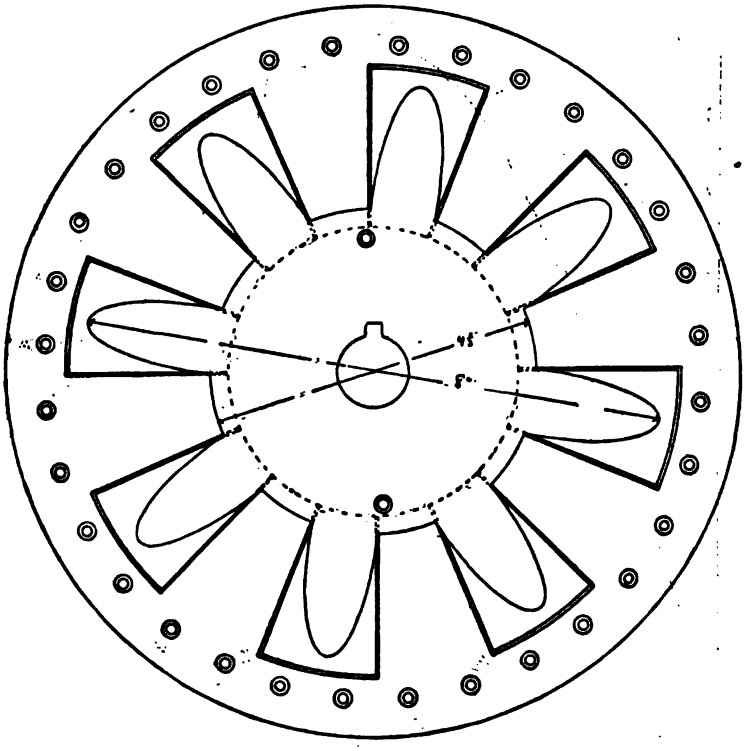


FIG. 3 FIELD MAGNET AND ARMATURE

desired. It has been run continuously at the rate of 3,000 revolutions per minute, without perceptible jarring.

The machine was at first supplied with a mechanical counter which could be thrown on or off by means of an electro-magnet operated by a key. We found, however, that the arrangement was unsatisfactory, as variations of speed were introduced by its friction and inertia. Moreover, such an arrangement gives only the average speed during a given time; we therefore abandoned this counter and adopted a

stroboscopic device. A ray of light is reflected upon the revolving segmented disk from a mirror attached to an electrically driven tuning-fork of known rate. With such an arrangement the desired speed may be attained and variations from it measured by noting the apparent motion of the disk.

The first test to which the apparatus was put was to obtain the

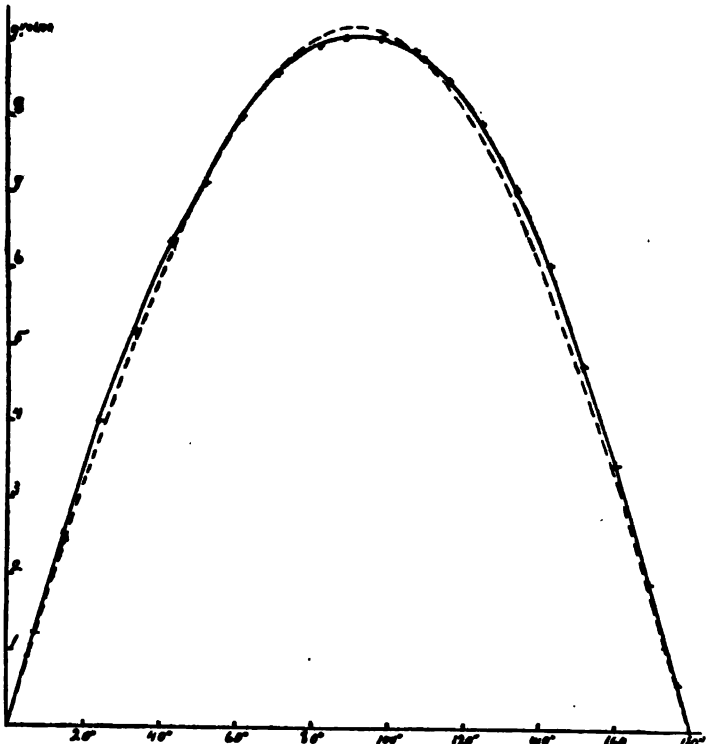


FIG. 4 ARMATURE A. TRUE SINE CURVE DOTTED.

judgment of a person having a trained ear as to the quality of the tone produced by its current in a telephone. His opinion was that the tone was pure, only the fundamental being detected. The wave form was then mapped.

In planning this work it occurred to us to employ the method of projection of potentials whenever it was necessary to measure a P. D. or E. M. F. at any instant. The opposing P. D. was obtained by the fall of potential due to the passage of a direct current through a suit-

able resistance. As the opposing P. D. was not alternating, the above mentioned contact arrangement was used in place of the ordinary key, and its value was determined by a suitable Weston voltmeter. This method of dealing with instantaneous E. M. F.'s was originally suggested by Professors Foster and Maxwell, their object being to obtain a balance between a known E. M. F. and the P. D.

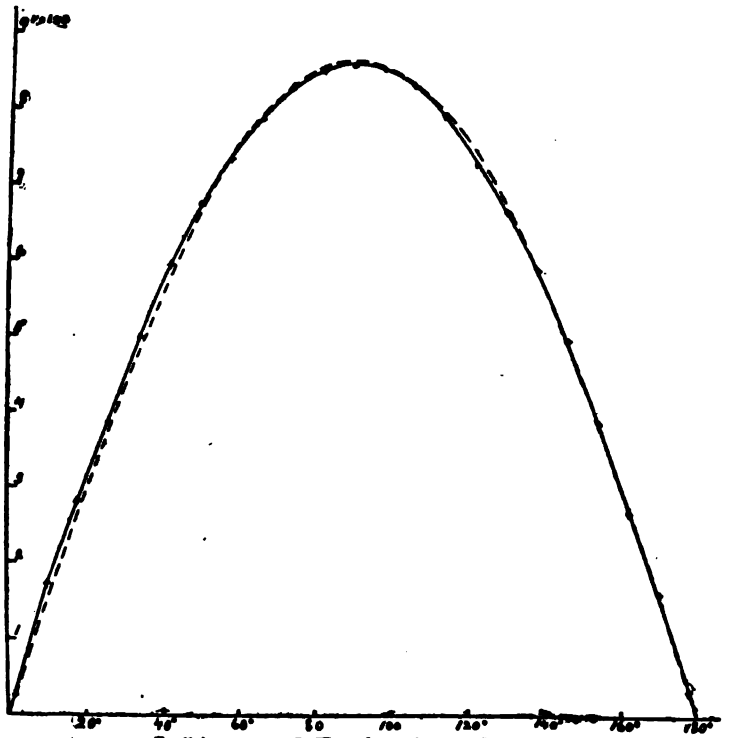


FIG 5 ARMATURE B. TRUE SINE CURVE DOTTED.

between the terminals of a resistance through which a current of known absolute magnitude was flowing.[1]

In order to obtain sensitiveness at the final balancing a condenser one microfarad in capacity was inserted in shunt with the galvanometer, the discharge of the condenser serving to increase the deflection. The galvanometer was of 3,000 ohms resistance. A telephone was used to obtain the preliminary balance. In Table I are given the

[1] Telegraphic Journal, 2, 1874, 317.

TABLE I. DETERMINATION OF WAVE FORM.

Armature A.			Armature B.	
Ampere turns, 2,875.			Ampere turns, 2,150.	
Speed, 1,465.				
Revs. of Mic. Head.	E. M. F. in volts.	Check.	Position of Contact.	E. M. F. in volts.
0	+ .49	+ .48	11°	+ 1.00
½	— .91	— 1.20	10	— .26
1	— 2.52	— 2.53	9	— 1.72
1½	— 4.01	— 4.01	8	— 2.80
2	— 5.21	— 5.19	7	— 3.86
2½	— 6.38	— 6.36	6	— 4.98
3	— 7.09	— 7.21	5	— 5.93
3½	— 8.04	— 8.03	4	— 6.75
4	— 8.61	— 8.61	3	— 7.34
4½	— 9.01	— 8.96	2	— 7.86
5	— 9.11	— 9.12	1	— 8.30
5½	— 9.12	— 9.12	360	— 8.50
6	— 8.95	— 8.94	359	— 8.56
6½	— 8.52	— 8.54	358	— 8.54
7	— 8.00	— 7.95	357	— 8.30
7½	— 7.09	— 7.08	356	— 7.91
8	— 6.11	— 6.12	355	— 7.26
8½	— 4.80	— 4.80	354	— 6.62
9	— 3.53	— 3.48	353	— 5.86
9½	— 1.94	— 1.96	352	— 4.93
10	— .60	— .60	351	— 3.85
10½	+ 1.12	....	350	— 2.67
....	....	....	349	— 1.60
....	....	....	348	— .32
....	....	....	347	+ .74

results of the determination of the wave forms of both dynamos, one section of 10 wires being used. In the case of armature A (movable) a series of checks is appended. The whole series was gone through with and then repeated in the reverse direction, the person making the readings not knowing the previous results. The most probable sources of deviation are backlash, variations of field current, and change of speed. The checks show sufficient precision of the apparatus for the method of procedure to be described presently.

These results are plotted together with true sine curves in Figures 4 and 5. The curves proved to be very nearly symmetrical, so that only one half has been given. The saturation curve connecting maximum E. M. F. and field current was taken with armature A. The results are given in Table II, and are plotted in Figure 6.

TABLE II. DATA OF SATURATION CURVE.

Speed, 1,465.	
Field Current in amperes.	E. M. F. in volts.
3.40	5.56
4.12	6.16
4.93	6.74
6.10	7.40
7.08	7.70
8.06	8.10
9.38	8.52
11.12	9.23
14.40	10.10
15.00	10.18

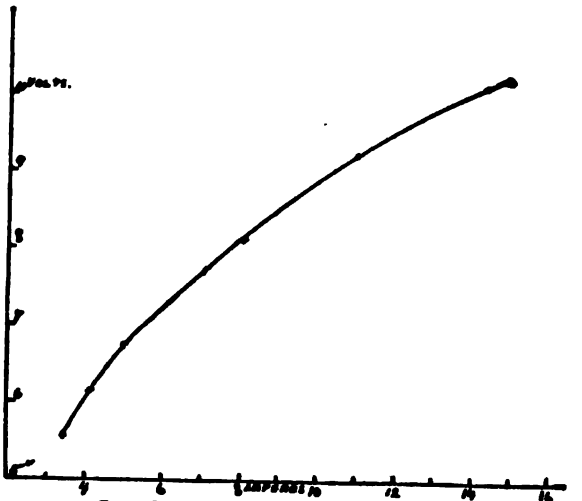


FIG. 6 SATURATION CURVE

METHODS OF USING THE MACHINE.

The following methods are all based on the assumption that we have a sinusoidal E. M. F. of known period, acting in a circuit containing only true resistances and inductances. The current at any instant will be expressed by the equation

$$i = \frac{E}{\sqrt{R^2 + P^2L^2}} \sin\left(Pt - \tan^{-1}\frac{LP}{R}\right)$$

The maximum value of the sine term being unity, we have

$$\frac{I}{E} = \frac{1}{\sqrt{R^2 + P^2L^2}}$$

I and E being the maximum current in, and maximum E. M. F. impressed upon the part of the circuit under discussion. Also the lag between current and E. M. F. is expressed by $\tan\theta = \frac{LP}{R}$. From these two equations we have

$$L = \frac{E}{IP}\sin\theta \qquad R = \frac{E}{I}\cos\theta$$

Our aim is, therefore, to obtain the values of the impedance, angle of lag, and frequency, and to calculate the coefficient of self-induction and the resistance for any given periodicity by the above formulæ.

(*a*) If we make up a circuit of the movable armature, a known resistance of negligible inductance, and the unknown coil, all in series, we may, by means of the measuring arrangement already mentioned, obtain E and I, the latter by the maximum P. D. around the known resistance. The angle θ would best be found by taking measurements on both sides of the zeros of current and E. M. F., and interpolating for the zero points. The difference of readings of the micrometer so obtained divided by 20 gives the angle θ. L and R are to be calculated by the above formulæ.

(*b*) If we have a carefully made plot like Figure 6 connecting the maximum E. M. F. and field current of one dynamo, we may proceed as follows: As the wave forms are alike, both following the sinusoidal law, we may apply Poggendorf's method of balancing E. M. F.'s directly, using a suitable telephone instead of a galvanometer. To do this make up a circuit of the stationary armature, known inductionless resistance, and unknown coil. Keep the field current of this dynamo constant. Attach the second armature through the telephone, first to the terminals of the known resistance. Adjust the phase relation for a minimum of sound in the telephone; then adjust for silence by varying the field current. Read the micrometer head and value of exciting current. Repeat this process at the terminals of the unknown coil. These measurements furnish the data necessary for the calculation of L and R. θ is given by difference of micrometer readings divided by 20, as before. Owing to lack of exact similarity of E. M. F. waves it would be necessary in practice to adjust by a minimum, annulling the fundamental.

(*c*) The trouble of taking the preliminary curve, as well as any uncertainty which its use may introduce, can be avoided by the connections shown in Figure 7.

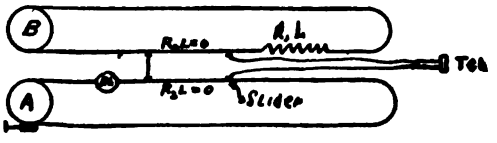


FIG. 7.

This method differs from the preceding only in the use of a derived E. M. F. for balancing and in the method of its adjustment. For convenience, give R_1 such a value that the P. D.'s around R_1 and R shall be about equal. Adjust the phase of armature A by the tangent screw, and adjust for amplitude by varying the field current, final adjustment being obtained by the slider.

Now change the connection to the terminals of the unknown coil, and again adjust for silence, making the adjustment for amplitude in this case by the slider alone. If the two values of the slider resistance are R_2 and R_3, then $\frac{I}{E} = \frac{R_2}{R_1 R_3}$. θ is given by the micrometer head as before.

(*d*) We may use a differential telephone, that is, a telephone having two opposed windings of equal influence and resistance, in the manner shown in Figure 8.

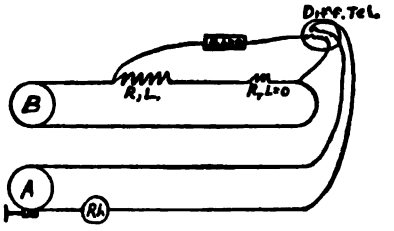


FIG. 8.

R_T is a resistance equal to that of one coil of the telephone and of negligible inductance. Adjustment is to be made until with the same value of i_A the telephone is silent when in place, as shown, and when interchanged with R_T then $R_1 = \frac{E}{I}$. θ is given by micrometer readings as before.

(*e*) We may also use the differential telephone to indicate when an unknown inductance is neutralized by a condenser of known variable capacity, by placing one of its coils in series with the inductance and condenser and the other in series with a variable inductionless resistance R_1, shunted around the above condenser, inductance and telephone coil, if the resistance R_1 and capacity C be varied until silence is obtained. Then $L = \frac{1}{CP^2}$ and $R = R_1$. It will be desirable

to employ an air-condenser to eliminate absorption effects, though this procedure has the disadvantage of requiring a very bulky and costly condenser when small inductances are to be measured.

With this apparatus we may also determine the electrostatic capacity of a condenser when not complicated by absorption effects. For instance, by the first method, we should insert in series with the condenser an inductionless resistance of such a magnitude that the angle of advance could be determined with accuracy.

Then

$$\frac{I}{E} = \frac{1}{\sqrt{R^2 + \frac{1}{C^2P^2}}} \qquad \tan\psi = \frac{1}{CRP}$$

$$C = \frac{I}{EP\sin\psi} \qquad R = \frac{E}{I}\cos\psi$$

If $R = 0$, $\psi = 90°$ and $C = \frac{I}{EP}$.

The above are the chief uses to which the apparatus may be put. We hope in the near future to investigate the transmission of telephonic and telegraphic signals, and to study various small induction coils such as are used in telephony, as well as the errors introduced into results by the above methods owing to lack of fulfillment of the assumed law by the E. M. F.

ROGERS LABORATORY OF PHYSICS,
September, 1893.

A NEW TORSION MACHINE.

By EDWARD F. MILLER, S.B.

Received January 8, 1894.

A NEW torsion machine capable of weighing the twisting moment necessary to twist off iron bars up to 3″ diameter, and of lengths varying from 1 to 8 feet, has recently been added to the Engineering Laboratories of the Institute.

The aim of this design was to make a machine which would be accurate, easy to operate, and which would allow of a change in length of the test piece. Figures 1 and 2, taken from a photograph, give a good idea of the machine. One end is bolted firmly to two 11″ x 18″ yellow pine floor beams 12″ on centers, and serves merely to apply the twist. This twist is carried through the specimen to a weighing head hung in a movable carriage made of heavy, hard pine timber. This carriage runs on tracks, and can be moved to accommodate different lengths of specimen.

THE TWISTING END.

Power is applied to the twisting end of the machine through a 4″ belt driving a 24″ pulley on the shaft A, Figure 1. This shaft has on the inner end a hand wheel for accurately adjusting the twisting moment when using micrometers. On the same shaft is a $6\frac{3}{4}$″ diameter pinion, gearing with a 48″ gear, 4″ face on the shaft B. This 48″ gear turns freely on B, and has bolted to it a $6\frac{1}{4}$″ pinion, which in turn gears with another 48″ gear on the shaft C. The shaft C carries a strong, shrouded pinion $10\frac{3}{4}$″ diameter, gearing with a 43″ gear, 6″ face, $2\frac{1}{4}$″ pitch keyed to B. These two gears are liable to have a pressure of 12,000 pounds come on one tooth. The main shaft, which is of steel, is $4\frac{1}{2}$″ diameter for about half its length, and is then turned down with

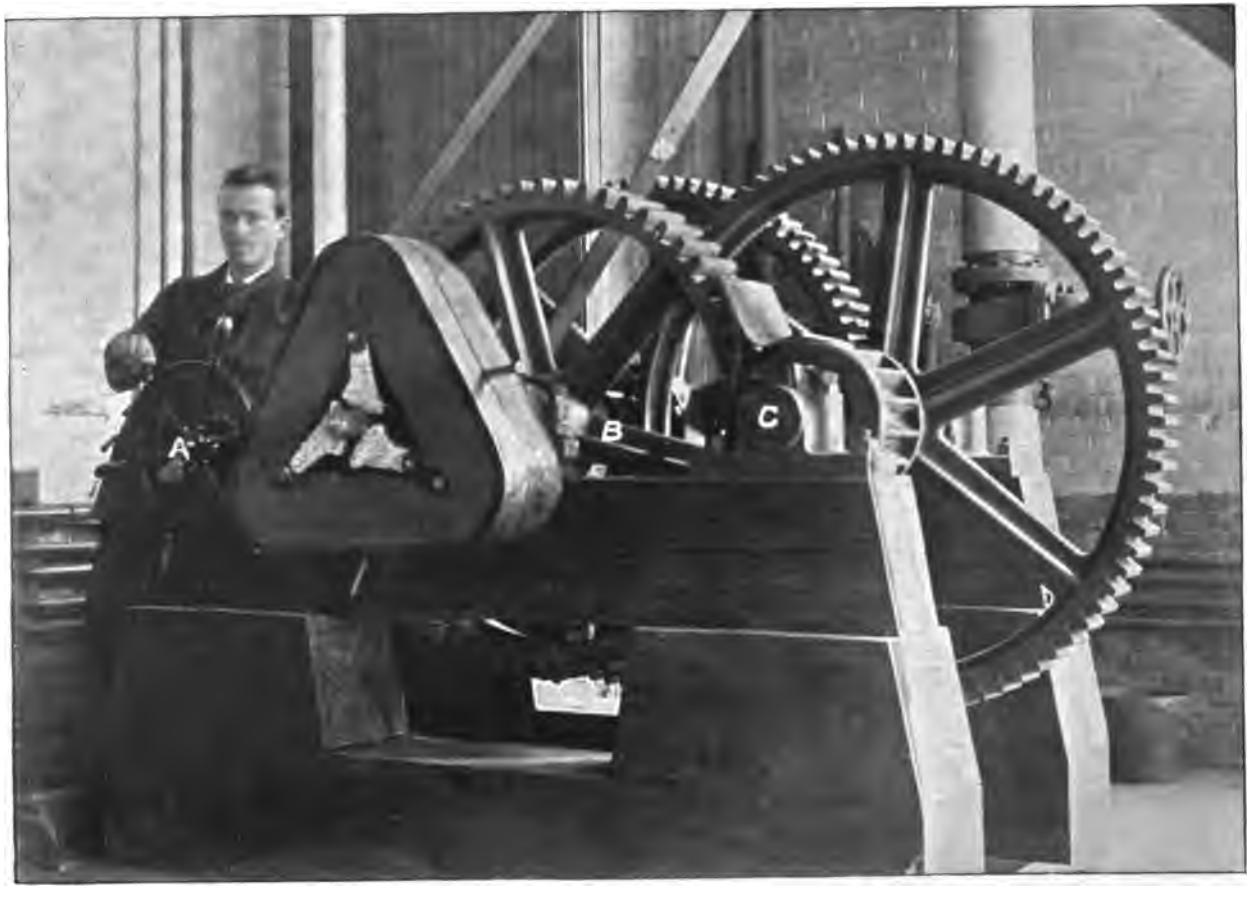


FIGURE 1.

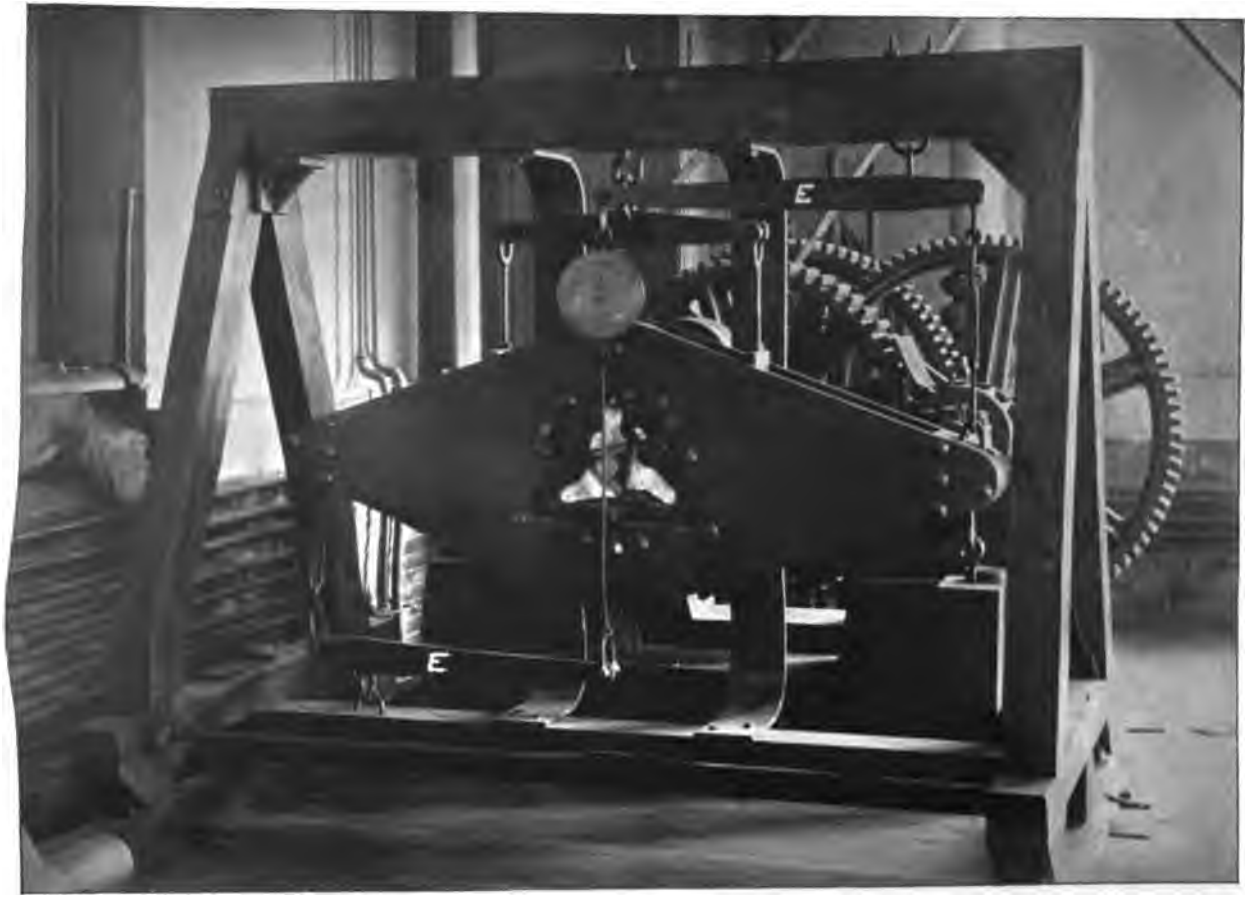


FIGURE 2.

FIGURE 3.

a round corner to $3\frac{1}{2}''$ diameter under the loose gear and pinion and through the outer bearing. One of the gripping holders is keyed to the inner end of the main shaft. This shaft, with holder and gears, weighs about 2,800 pounds. The end thrust of the last train of gears is taken from the frame by two ties of $3'' \times \frac{1}{2}''$ iron joining the boxes of the shafts B and C.

The frame supporting the shafts is made of $12'' \times 12''$ and $8'' \times 12''$ hard pine timber keyed and bolted together, the bottom of the frame being spread to about six feet. There is a certain amount of force tending to turn this frame as a whole about one end, but the weight of the shafts and gears is enough to overbalance this. There are two sets of pulleys on the overhead countershaft, one set giving twice the speed of the other.

The total multiplication both in the countershaft belting and in the gears is for the slower speed.

$$\frac{24}{3} \times \frac{24}{10} \times \frac{48}{6.75} \times \frac{48}{6.25} \times \frac{43}{10.75} = \frac{4194}{1} \text{ or about 4194 to 1.}$$

The speed of the engine shafting is about 290 revolutions per minute, so that the twisting holder turns once in about $14\frac{1}{2}$ minutes.

THE WEIGHING END.

The carriage at the weighing end rests on four flanged truck wheels running on I beam tracks firmly bolted to the floor. To prevent the whole carriage from overturning, there are two hold-down wheels on one side, which bear against the under side of the upper web of the I beam. These wheels have but a small load at the full capacity of the machine. The bottom of the carriage is spread to about four feet, in order to prevent cramping on the tracks. The tracks are carried beyond the inner frame of the twisting end, so that the carriage may be brought up to the holder.

The weighing head (Figure 2) is supported by an equal armed lever hung from the top of the carriage. This head consists of two pieces of steel, $\frac{1}{2}''$ thick and $80''$ long, shaped as shown in the figure, with a gripping holder at the center and castings at either end riveted in between them. In each of the end castings there is a knife edge, the point of the knife edge pointing in the direction that that end tends to turn. These knife edges are connected to two levers (EE), one at the

top and one at the bottom of the carriage, in such a way that the inner ends of these levers separate when a twist is applied. These levers are not exactly in the plane of the weighing head, the fixed fulcrum being moved so that the free ends of the levers swing clear of the weighing head. One spring balance takes the pull of both levers. By this means the forces at the two end knife edges are equal, opposite, and parallel, thus forming a couple. The twisting moment is then the force at a knife edge times 72, the distance between the knife edges in inches; and as the levers give a multiplication of 5 to 1, the pull at the spring balance times 360 (5 x 72) gives in inch-pounds the twisting moment on the specimen. It might be said that as the spring balance pulls out the levers will be thrown out of level; but a load of 300 pounds causes a motion of only $1\frac{1}{4}''$ at the spring balance, and the end of the lever of the weighing head is thrown out but $\frac{12}{100}''$. All the knife edges in the weighing head, as well as those in the levers, are placed in line, so that the error introduced is inappreciable.

The manner of suspending the weighing head allows of a bending or of a change in length of the specimen under test without throwing any new strains into it. The spring balance measuring the pull on the levers is shortly to be replaced by a lever and sliding weight graduated to read twisting moments directly.

On the inside of the carriage there are four wheels 10″ diameter, 1″ thick, turning on small studs screwed into two castings which can be moved sideways and clamped to uprights of $6'' \times \frac{1}{2}''$ iron lag screwed to the carriage. These wheels prevent too much side motion being given to the weighing head. They are used only when pieces bend or twist out of shape. As the wheels are large compared with the pivots, there is but little error introduced, and generally they are not used until after the maximum has been passed and the piece has begun to fail.

THE TWISTING HOLDER.

The twisting holder is a heavy, triangular-shaped casting, having a hub on one side and a triangular-shaped recess running back about 8″ on the other side. At the three angles of this triangular opening are flattened bearing surfaces, on each of which rests a rectangular block grooved on the inner side to furnish a bearing for a toggle grip. The toggle grip is made of cast iron, with a toothed cast-steel plate about $\frac{1}{2}''$ thick at its acting face.

The acting face is an arc of a circle, the center from which the arc is struck being to one side of the bearing end of the grip. This enables one set of grips to take different sizes, and also prevents the toggle from straightening. This center is so taken that no matter what the size of specimen the angle of the toggle is nearly the same. It is evident that the greater the twist the harder the toggles grip.

For fear that in case a specimen should break off in the grips, the grips might fail to release, a steel wedge was placed in a recess in the holder casting under one of the bearing blocks. The wedge was made at about the angle of friction, and was kept from being pressed back by a nut and screw attached to it, the nut bearing on the casting. By unscrewing the nut and tapping the wedge back the jaws are loosened.

A number of specimens of 2″ diameter Norway iron have broken at the edge of the twisting holder, but in every case the jaws have released without the use of the wedge. For convenience in centering a specimen, three screws run through the casting and bear against the toggles.

On account of the enormous end pressure on the toggles, the holder casting was made heavy and was reinforced by two bands of 3″ x 1″ wrought iron shrunk on the outside. To better resist the strains the casting was made triangular-shaped. The holder in the weighing end is similar to the other, except that there is no hub, the triangular opening running way through the casting. Working drawings of some of the parts of the gripping holder are given in Plate 2.

MEASURING APPARATUS.

To find the shearing modulus of elasticity it is necessary to know the increase in the angle of twist for a certain increase in the twisting moment. The measuring apparatus made use of in finding the angle of twist is a slight modification of a style previously used in the laboratory. Drawings of it are shown in Plate 1. It consists of a piece of 4″ brass pipe about 54″ long, split longitudinally, and fastened together by means of bolts in castings at the ends.

At one end three pointed screws run through the casting and grip into the specimen. At the other end the brass pipe projects through a casting carrying an arm 24″ long, and rests in another similar casting fastened to the specimen by screws which go through elongated holes in the brass pipe. The pipe is free to turn in this last casting

and is also held up in place by it. One of these arms will turn with one part of the specimen, and the other arm with a part 50″ distant, 50″ being the distance between the set screws gripping into the specimen. The amount the two arms separate is measured by a micrometer carried by one of the arms. The chord thus measured is practically the same as the arc. Contact between the micrometer points is shown by a galvanometer.

Following is a sample log for recording readings and also results of some of the tests made by the fourth-year students on 2″ diameter bars of Norway and refined iron. The fractures show very plainly the quality of the iron. Some of the Norway bars twisted 16½ turns in a length of six feet. White stripes are painted on the bars before testing. A few of the fractured bars are shown in Figure 3.

TORSION MACHINE.

No. 8. November 6, 1893.

Specimen, Norway Iron.
Diameter, 2.02 inches. Length between jaws, 72 inches.
Distance from micrometer to center of test piece, 24.27 inches.
Distance apart on test piece of points between which arc of twist is measured, 50 inches.

Scale Reading.	Twisting Moment.	Micrometer Readings.				Mean.	Difference.	Remarks.
		1.	2.	3.	4.			
15	5,400	.3659	.3656	.3658	.3659	.3658	.....	Turned 16 times.
25	9,000	.1608	.1605	.1605	.1606	.1606	.2038	Stopped at 4.15, November 6, with a load on scale of 143 lbs.
35	12,600	—.0430	—.0430	—.0430	—.0430	—.0430	.2036	
35	12,600	.9297	.9295	.9294	.9296	.9296	.....	Broken November 7 at load of 208.25 on scale.
45	16,200	.6903	.6904	.6902	.6904	.6903	.2393	

Maximum load by scale . . . . . 208.25 pounds.
Maximum twisting moment . . . . . 74,970 inch-pounds.
Greatest outside fiber stress . . . . . 46,600 pounds.
Shearing modulus of elasticity (5400–9000) . . . . . 13,215,000.
Modulus of elasticity by tension test . . . . .

Signed.....

Kind of Iron.	Diameter in Inches.	Maximum Twisting Moment.	Maximum Outside Fiber Stress.	Shearing Modulus of Elasticity.	Number of Turns.	Distance between Grips.
Refined . .	2.03	84,240	51,285	12,471,000	4	72.1″
Refined . .	2.03	66,960	40,646	12,576,000	1.25	71.2″
Refined . .	2.03	70,200	41,743	11,372,000	3.5	70.5″
Refined . .	2.03	72,000	43,834	10,960,000	2.3	72.1″
Refined . .	2.03	61,920	36,820	11,393,000	2.8	71.8″
Refined . .	2.03	68,760	40,887	11,360,000	2.5	71.3″
Refined . .	2.03	78,120	46,453	12,871,000	2.8	69.3″
Norway . .	2.00	72,360	46,065	11,406,000	16.5	70.4″
Norway . .	2.02	74,970	46,600	13,215,000	16	72″
Norway . .	2.03	72,000	43,757	12,902,000	14	71.3″
Norway . .	2.02	74,520	46,321	12,247,000	17	70.4″
Norway . .	2.02	72,000	45,837	12,738,000	14.3	69.8″
Norway . .	2.03	74,880	45,692	11,361,000	15.5	70.3″

MATRICES WHICH REPRESENT VECTORS.

By W. H. METZLER, PH.D.

Received January 24, 1894.

SECTION I.

The matrix

$$\phi = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

may be considered as the quaternion

$$\frac{a_{11}(1-\lambda i)}{2} + \frac{a_{12}(j-\lambda k)}{2} + \frac{a_{21}(-j-\lambda k)}{2} + \frac{a_{22}(1+\lambda i)}{2}$$

or

$$\frac{a_{11}+a_{22}}{2} - \frac{\lambda(a_{11}-a_{22})}{2} i + \frac{(a_{12}-a_{21})}{2} j - \frac{\lambda(a_{12}+a_{21})}{2} k \,*$$

where $\lambda = \sqrt{-1}$.

If the matrix ϕ is real, the quaternion will in general be imaginary. If, however, $a_{11} = a_{22}$ and $a_{12} + a_{21} = 0$, the quaternion will be real and reduce to $a_{11} + a_{12} j$. If a_{11}, a_{22} are conjugate imaginary of the form $a \pm \lambda b$, and a_{12}, a_{21} are conjugate imaginary of the form $\lambda c \pm d$, the quaternion will be real.

Let

$$\phi = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \quad \text{and} \quad \psi = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix},$$

then

$$\phi\,\psi = \begin{pmatrix} a_{11}b_{11} + a_{12}b_{21} & a_{11}b_{12} + a_{12}b_{22} \\ a_{21}b_{11} + a_{22}b_{21} & a_{21}b_{12} + a_{22}b_{22} \end{pmatrix}$$

and it is easily seen that the product of the quaternions ϕ and ψ is the same as the product of the matrices ϕ and ψ considered as a quaternion.

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* *Vide* paper by Professor Cayley, Messenger of Mathematics, 14, 176.

The conjugate of the quaternion ϕ is

$$\frac{a_{11}+a_{22}}{2}+\frac{\lambda(a_{11}-a_{22})}{2}i-\frac{(a_{12}-a_{21})}{2}j+\frac{\lambda(a_{12}+a_{21})}{2}k,$$

which may be obtained from ϕ by changing the signs of a_{12}, a_{21}, and interchanging a_{11}, a_{22}, *i. e.*,

$$\mathrm{K}\,\phi=\begin{pmatrix} a_{22} & -a_{12} \\ -a_{21} & a_{11} \end{pmatrix}$$

The tensor of ϕ is given by

$$\begin{aligned}\mathrm{T}\,\phi&=\sqrt{\frac{(a_{11}+a_{22})^2}{4}+\frac{\lambda^2(a_{11}-a_{22})^2}{4}+\frac{(a_{12}-a_{21})^2}{4}+\frac{\lambda^2(a_{12}+a_{21})^2}{4}}\\&=\sqrt{a_{11}a_{22}-a_{12}a_{21}}\\&=\sqrt{g_1g_2}.\end{aligned}$$

If g_1, g_2 are the latent roots of ϕ, then $g_1+g_2=a_{11}+a_{22}$ and $\mathrm{S}\,\phi=\frac{a_{11}+a_{22}}{2}=\frac{g_1+g_2}{2}$. The matrix ϕ will represent a vector if $\mathrm{S}\,\phi=0$, and therefore $a_{11}=-a_{22}$. We may then write the vectors

$$\phi=\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & -a_{11} \end{pmatrix}=\lambda a_{11}i+\frac{(a_{12}-a_{21})}{2}j-\frac{\lambda(a_{12}+a_{21})}{2}k$$

and

$$\psi=\begin{pmatrix} b_{11} & b_{12} \\ b_{21} & -b_{11} \end{pmatrix}=\lambda b_{11}i+\frac{(b_{12}-b_{21})}{2}j-\frac{\lambda(b_{12}+b_{21})}{2}k.$$

$$\text{The }\cos\hat{\phi\psi}=\frac{-a_{11}b_{11}+\frac{(a_{12}-a_{21})(b_{12}-b_{21})}{4}-\frac{(a_{12}+a_{21})(b_{12}+b_{21})}{4}}{\mathrm{T}\,\phi\,.\,\mathrm{T}\,\psi}$$

$$=\frac{-2a_{11}b_{11}-a_{12}b_{21}-a_{21}b_{12}}{2\,\mathrm{T}\phi\,.\,\mathrm{T}\psi}.$$

In order that ϕ and ψ are vectors at right angles to each other, we must have

$$2a_{11}b_{11}+a_{12}b_{21}+a_{21}b_{12}=0.$$

And since

$$\phi\psi=\begin{pmatrix} a_{11}b_{11}+a_{12}b_{21} & a_{11}b_{12}-a_{12}b_{11} \\ a_{21}b_{11}-a_{11}b_{21} & a_{21}b_{12}+a_{11}b_{11} \end{pmatrix},$$

we see that the condition that ϕ and ψ are vectors at right angles to

each other is the same as the condition that $\phi\,\psi$[1] is a vector, and it may be easily shown that $\chi = \phi\,\psi$ is a vector perpendicular to the plane of the vectors ϕ and ψ.

If ϕ is a unit vector, then

$$T\,\phi = -\,a_{11}^2 - a_{12}\,a_{21} = 1 = -\,\phi^2;$$

and if ϕ and ψ are unit vectors at right angles to each other, then $\phi\,\psi$ is a unit vector perpendicular to their plane.

If we take

$$\phi_1 = \begin{pmatrix} \sqrt{-1} & 0 \\ 0 & -\sqrt{-1} \end{pmatrix},$$

$$\phi_2 = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix},$$

$$\phi_3 = \begin{pmatrix} 0 & \sqrt{-1} \\ \sqrt{-1} & 0 \end{pmatrix},$$

then

$$\phi_1\,\phi_2 = -\,\phi_2\,\phi_1 = \phi_3,$$
$$\phi_2\,\phi_3 = -\,\phi_3\,\phi_2 = \phi_1,$$
$$\phi_3\,\phi_1 = -\,\phi_1\,\phi_3 = \phi_2,$$
$$\phi_1^2 = \phi_2^2 = \phi_3^2 = -\,1 \text{ and } \phi_1,\ \phi_2,\ \phi_3$$

will form a rectangular system of unit vectors, which are i, j, k, respectively.

Any matrix of the second order may be expressed in terms of these three and the matrix unity, so any quaternion may be expressed in terms of these three vectors and unity. We might, therefore, base the study of quaternions on that of matrices of the second order.

Matrices of any order may, in a similar way, be divided into a scalar and vector part. If ϕ is a matrix of order ω, then

$$S\,\phi = \frac{g_1 + g_2 + g_3 + \cdots + g_\omega}{\omega},$$

where $g_1, g_2, g_3 \ldots g_\omega$ are the latent roots of ϕ, and any matrix, the sum of whose latent roots equals zero represents a vector.

SECTION 2.

A matrix of the third order, considered as operating on a vector, gives a vector the components of which along the three axes are linear

[1] It is apparent that the condition that $\phi\,\psi$ is a vector is the same as the condition that $\psi\,\phi$ is a vector.

functions of the components of the original vector, and the matrix is called a linear vector function or operator.

Matrices having all their constituents zero except those along the principal diagonal are commutative in multiplication.

If we take

$$\phi = \begin{pmatrix} x & 0 & 0 \\ 0 & y & 0 \\ 0 & 0 & z \end{pmatrix} \text{ and } \rho = i + j + k,$$

then $\phi\rho = xi + yj + zk = \rho'$; that is, any vector whatever whose rectangular components have the lengths x, y, z, may be derived from ρ, whose rectangular components have the lengths 1, 1, 1, by operating on it by the matrix ϕ. From this we see that the study of vectors may be made to depend on that of such matrices as ϕ.

The treatment of vectors in this way is given in a paper by Dr. C. H. Chapman in the *American Journal of Mathematics*, Vol. XIII, No. 4. Through his paper Dr. Chapman speaks of the matrix ϕ, and the vector $\phi\rho = xi + yj + zk$ as the same; and the vector $\phi\psi$ is defined to be a new vector whose component lengths are the products of those of the factors, and consequently may be represented by the matrix $\phi\psi$. With this definition vectors are commutative, and on this ground the greatest claim is made by the author for this method of treatment.

It is to be observed that the symbol cy there introduced is the same as the symbol K employed by Dr. Taber in his paper *American Journal of Mathematics*, Vol. XII, No. 4, and is the extension of the quaternion (dual matrix) symbol K to matrices of the third order (nonions).

It strikes one on reading the paper that the advantages gained by this method, ingenious as it may be, are, on the whole, more than counterbalanced by its disadvantages.

THE EFFICIENCY OF JACK-SCREWS.

BY EDWARD F. MILLER, S.B., AND WILLIAM A. JOHNSTON, S.B.

Received February 26, 1894.

DURING the past four months quite a number of tests on jack-screws have been made in the Engineering Laboratories of the Massachusetts Institute of Technology. Some of these tests were made by the students as a part of the regular laboratory work, but the greater part were made by the writers. The tests were divided into three sets, three different kinds of oil being used to lubricate the jacks.

The results are interesting as showing how low the efficiencies are, and what increase in efficiency is obtained by using ball bearings between the head and cap or under the nut.

The test consisted in finding the pull at the end of a lever of known length necessary to lift a certain load on the jack. In all of the tests the pull given is the force necessary to start the jack, the pull after starting always being less.

$$\text{The efficiency} = \frac{\text{load} \times \text{pitch of screw in inches}}{3.1416 \times 2 \times \text{lever in inches} \times \text{pull}}.$$

Instead of using dead weights to load the jack, an apparatus consisting of I beams and levers was made, by means of which a load of 15,000 pounds could be obtained with 48 pounds on the weighing arm. The apparatus made is shown in Figure 1; although crude in appearance it is quite accurate. Two 8″ I beams fastened together are hung from two more I beams resting on wooden horses. These lower beams rest at one end on a knife edge *A* and at the other end on a knife edge *B* attached to the weighing beam. The jack is placed at *C*, one tenth the distance *AB* from *A*. The bottom of the jack bears on a plate which rests on the knife edge *C*. The lower I beams serve as a lever, giving a multiplication of 10 to 1. The weighing lever is a steelyard,

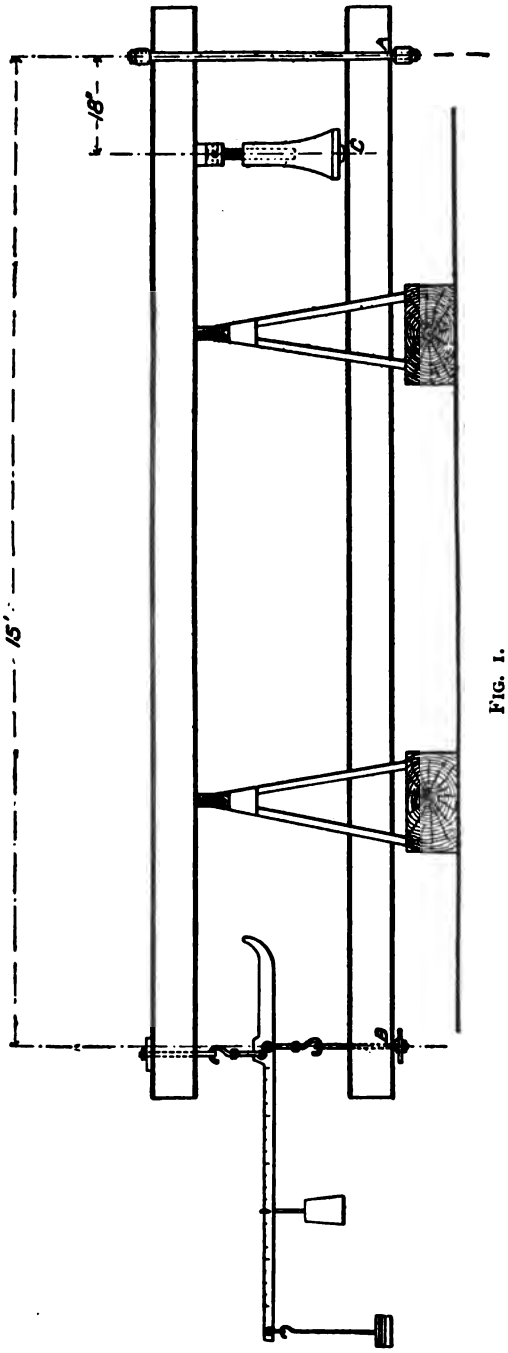

FIG. 1.

multiplying 31.25 to 1, so that the total multiplication of the two levers is 312.5. The weight of the jack and free end of the I beam lever is counterbalanced by weights placed in a scale pan hung from a knife edge at the end of the steelyard. The middle knife edge *C* is 8″ above the other two. This would cause an error if the lever had much motion, but as the extreme motion of the knife edge *B* is but $\frac{2}{10}$ of an inch there can be no appreciable error from this cause. The apparatus was tested, to see if the multiplication was correct, by resting a pair of platform scales on the knife edge *C* and applying a load of 2,000 pounds by means of a jack. The indication by the steelyard agreed with that shown by the scales.

In making a test the jack is screwed up until the steelyard is horizontal with the required load, then a steadily increasing pull is applied, through a spring balance, to the end of the lever until the lever moves. When the lever operating the jack moved in a vertical plane, an allowance was made for the weight of the lever, and this allowance added to the pull by the balance. The spring balances used in these tests were tested frequently with standard weights and corrections applied.

In the following tables the values given under the heading "average pull" are each the average of about five observations.

Jacks Nos. 1 and 5. Screw $2\frac{1}{4}$″ outside diameter cut with bastard thread $\frac{3}{10}$″ pitch. The annular ring at the head of the jack bearing against the cap is 3″ outside diameter, 1″ inside diameter.

Jacks Nos. 2 and 3. Screw 2″ outside diameter, $\frac{1}{4}$″ pitch square thread. Bearing ring at the cap is 3″ outside diameter, $1\frac{3}{4}$″ inside diameter.

Jack No. 4. Screw 2″ outside diameter, $\frac{1}{4}$″ pitch square thread. Cap is 3″ diameter, and bears all over.

Jack No. 6. Screw $2\frac{3}{8}$″ outside diameter, cut $\frac{1}{2}$″ pitch square thread. Bearing ring at cap 3″ outside diameter, $1\frac{1}{4}$″ inside diameter.

Jack No. 7. Screw $2\frac{7}{16}$″ outside diameter, $\frac{1}{4}$″ pitch square thread. The screw of this jack does not turn, but is forced upward by means of a nut bearing on the casting outside of the screw. This nut has ratchet teeth on its outer circumference, and is operated by a pawl and lever, the pawl being reversed to run the jack down. Between the nut and the casting there is a ball bearing. The cylindrical casting carrying the pawl protects the ball bearing from sand or dust.

Jacks Nos. 8, 9, 10 and *11.* The screws of these jacks are $1\frac{1}{2}$″ outside diameter and $\frac{1}{4}$″ pitch. The screw is somewhat peculiar, it

being cut flat on the bottom or bearing side and beveled to the base of the next thread on the upper side. The main casting or base to which the screw carries the load is turned cylindrical down to the foot, and serves as a guide for an outer cylindrical casting moved by the screw. This outer casting protects the parts from dust, and, as it takes all bending strains from the screw, renders the use of a screw of small diameter possible. Near the top of the outer casting there is a ratchet wheel, connected inside the casing with a bevel gear which in turn engages with another bevel gear fastened to the head of the screw. Between this bevel gear and the top of the outer casing there is a ball bearing. The ratchet is operated through the working lever by means of a double-ended pawl, which can be made to engage on either the up or the down stroke.

FIG. 2.

It will be seen by referring to the tables that the maximum variation from the average pull was greatest in the cases of Nos. 8, 9, and 11. This was probably due to inequalities in the teeth of the cast bevel wheels which turn the screw. In the case of Jack No. 10 the variation was so great that the results were not quoted.

JACK NUMBER 1.

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	24.70	.6	3	16.8		3,000	25.45	.55	3	16.3		3,000	26.4	.2	3	15.7	
	24.30	.6	3	17.0	16.9		28.90	.90	3	14.4			24.1	.9	3	17.2	16.4
							28.30	.70	3	14.7	15.1						
5,000	41.40	.2	3	16.7		5,000	41.62	2.4	3	16.6		5,000	40.2	1.3	3	17.2	17.3
	41.20	.5	3	17.2	16.9		47.65	.85	3	14.5			39.9	.4	3	17.3	
							46.00	.75	3	15.0	15.4						
7,000	70	.2	6	16.8		7,000	58.45	1.6	3	16.5		7,000	55.5	.5	3	17.4	
	2.00	.3	6	17.3	17.0		30.10	.4	6	16.1			54.5	1.0	3	17.8	17.6
							30.10	.6	6	16.1	16.2						
9,000	37.75	.3	6	16.5		9,000	36.40	1.5	6	17.1		9,000	34.1	.2	6	18.2	
	38.55	.3	6	16.1	16.3		38.80	.7	6	16.0			34.5	.5	6	18.0	18.1
							37.85	1.2	6	16.4	16.5						
11,000	47.70	.2	6	15.9		11,000	46.35	1.2	6	16.4		11,000	41.5	.5	6	18.3	
	45.75	.3	6	16.6	16.2		46.00	.75	6	16.5			41.0	.5	6	18.5	18.4
							45.80	1.2	6	16.6	16.5						
13,000	54.90	.9	6	16.4		13,000	53.75	.75	6	16.7		13,000	49.9	.6	6	18.0	
	55.05	.5	6	16.3	16.4		54.90	.90	6	16.4			47.0	.5	6	19.1	18.6
							53.25	.75	6	16.9	16.7						
15,000	57.50	.5	7	15.7		15,000	57.10	2.1	7	15.6		15,000	56.5	.5	6	18.3	
	57.10	.5	7	15.6	15.7		59.90	.6	6	17.3			55.9	.9	6	18.5	18.4
							52.97	.7	7	16.8	16.6						

JACK NUMBER 2.

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
1,000	8.38	.6	3	10.5													
	7.92	.4	3	14.0	12.2												
3,000	27.17	1.2	3	12.2		3,000	27.6	1.4	3	12.0		3,000	24.6	.6	3	13.5	....
	27.36	.8	3	12.1	12.2		26.4	1.6	3	12.6	12.3						
5,000	44.00	.5	3	12.6		5,000	47.6	1.4	3	11.6		5,000	43.8	1.2	3	12.6	...
	43.44	1.4	3	12.7	12.6		42.2	3.6	3	13.1	12.3						
7,000	31.32	.7	6	12.4		7,000	31.6	.4	6	12.2		7,000	57.0	1.0	3	13.6	....
	30.44	1.4	6	12.7	12.5		30.0	1.0	6	12.9	12.5						
9,000	41.60	.4	6	12.0		9,000	41.0	1.0	6	12.1		9,000	35.8	.8	6	13.8	....
	40.06	1.0	6	12.4	12.2		39.0	1.0	6	12.8	12.4						
11,000	50 83	1.7	6	12.0		11,000	47.4	.6	6	12.8		11,000	45.3	.8	6	13.4	....
	48.22	1.2	6	12.6	12.3		47.0	2.0	6	12.9	12.8						
13,000	50.75	.8	7	12.1		13,000	56.8	.8	6	12.6		13,000	52.2	.8	6	13.7	....
	50.32	1.3	7	12.2	12.2		55.2	.8	6	13.0	12.8						
15,000	58.42	.6	7	12.2		15,000	55.2	1.2	7	12.9		15,000	57.9	.6	6	14.3	....
	57.17	1.2	7	12.4	12.3		55.2	1.2	7	12.9	12.9						

JACK NUMBER 3.

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads. (Pounds.)	Av. pull on lever. (Pounds.)	Maximum variation from average. (Pounds.)	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
1,000	10.86	.9	3	11.1													
	11.50	.5	3	9.6	10.3												
3,000	36.21	1.2	3	10.0		3,000	31.1	2.9	3	10.7		3,000	31.3	1.3	3	10.6	....
	37.20	.8	3	8.9	9.5		30.2	1.7	3	11.0	10.8						
5,000	58.50	1.5	3	10.3		5,000	41.5	2.5	4	10.0		5,000	53.9	.9	3	10.3	....
	57.33	1.7	3	9.6	9.9		50.2	2.7	3	11.0	10.5						
7,000	39.62	1.6	6	9.8		7,000	41.0	2.0	5	11.6	11.6	7,000	39.4	.3	6	9.8	...
	39.17	2.9	6	9.9	9.9												
9,000	53.82	.8	6	9.2		9,000	44.4	3.6	6	11.2		9,000	49.6	.4	6	10.0	....
	50.62	2.6	6	9.8	9.5		42 7	1.3	6	11.6	11.4						
11,000	52.67	1.3	7	10.0		11,000	52.1	3.9	6	11.7	11.7	11,000	54.1	.4	6	10.1	....
	51.58	2.5	7	10.1	10.0												
13,000	....	....	....	....	....	13,000	52.4	3.6	7	11.8		13,000	....	....	....	....	....
							54.8	4.8	7	11.2	11.5						
15,000	....	....	....	....	....	15,000	....	....	....	....	....	15,000	....	....	....	....	....

JACK NUMBER 4.

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average Efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from advance.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
1,000	9.05	.3	3	12.2								3,000	24.8	.8	3	13.4	
	8.64	.9	3	12.8	12.5								22.8	.1	3	14.3	
													20.8	.2	3	16.8	14.8
3,000	27.00	1.0	3	12.3		3,000	22.4	.6	3	14.8							
	26.58	.6	3	12.4	12.4		28.2	1.8	3	11.8	13.3	5,000	40.4	.9	3	13 7	
													20.5	.1	6	13.5	
5,000	44.20	1.2	3	12.5		5,000	37.4	.6	3	14.8			22.1	.1	6	12.3	13.1
	44.22	.8	3	12.5	12.5		45.9	2.5	3	12.0	13.4						
												7,000	59.1	.6	3	13.1	
7,000	57.70	1.7	3	13.4		7,000	25.6	.6	6	15.0			30.2	.3	6	12.8	
	59.25	.7	3	13.1	13.2		31.8	2.7	6	12.2	13.6		29.5	.3	6	13.1	13.0
9,000	37.40	.6	6	13 3		9,000	32.4	.6	6	15.4		9,000	36.8	.8	6	13.5	
	36.40	1.5	6	13.7	13.5		41.5	1.5	6	12 0	13.7		30.5	.1	7	14.0	
													29.7	.5	7	14.3	13.9
11,000	46.40	1.4	6	13.1		11,000	39.2	2.8	6	15.5							
	45.50	.5	6	13.4	13.2		48.1	1.1	6	12.6	14.0	11,000	46.1	.4	6	12 7	
													26.3	.1	10	13.9	
13,000	54.50	.5	6	13.2		13,000	46.3	2.7	6	15.5			23.7	.2	10	15.4	14.0
	52.58	1.4	6	13 6	13.4		53.3	1.7	6	13.5	14.5						
												13,000	51.9	.4	6	13.9	
15,000	54.20	.8	7	13.1		15,000	48.2	1.2	7	14.7			29.0	.5	11	13.5	
	53.70	.7	7	13.2	13.1		48.2	3.2	7	14.7	14.7		25.7	.3	11	15.2	14.2
.....	.....	....	....	....	....	.....	.....	....	....	....	....	15,000	59.2	.8	6	14.0	
													30.4	.1	12	13.6	
													30.5	.1	12	13.6	13.7

JACK NUMBER 5.

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	25.90	.9	3	16.0		3,000	29.00	1.0	3	14.3		3,000	23.0	.1	3	18 0	
	26.60	.6	3	15.6	15.8		26.95	.7	3	15.4			19.4	.3	3	21.4	19.7
							25.45	.3	3	16.3							
							25.05	.3	3	16.2							
							26.40	.6	3	15 7							
							26.60	1.4	3	15.6	15.6						
5,000	42.30	.7	3	16.3		5,000	43.65	1.7	3	15.8		5,000	18.8	.3	6	18 4	
	43.83	.4	3	15.8	16.0		41.10	.5	3	16.8			15.9	.2	6	21.7	20.0
							41.60	.4	3	16.6							
							39.60	.2	3	17.4							
							41.60	1.4	3	16.6							
							42.20	1.8	3	16.4	16.6						
7,000	29.70	.7	6	16.3		7,000	32.75	1.3	6	14.8		7,000	26.7	.3	6	18.1	
	30.65	.3	6	15.8	16.0		27.55	.6	6	17.6			23.0	.4	6	21.1	19.6
							56.75	.3	3	17.0							
							56.15	1.2	3	17.2							
							29.20	1.2	6	16.6							
							28.00	...	6	17.3	16.7						
9,000	41.60	.6	6	15.0		9,000	43.65	1.7	6	14.2		9,000	27.9	.2	7	19.1	
	41.60	.6	6	15.0	15.0		39.95	1.0	6	15.6			24 0	.5	7	22.2	20.6
							37.80	.4	6	16.4							
							35.80	.8	6	17.0							
							37.40	1.4	6	16.6							
							36.60	.6	6	17.0	16 1	....	....	....	....	....	....

JACK NUMBER 5.— *Concluded.*

Light Oil.						Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from advance.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
11,000	49.4	.6	6	15.4		11,000	52.90	1.4	6	14.4		11,000	23.7	.2	10	19.2	
	49.3	.8	6	15.4	15.4		39.00	3.0	7	19.5			21.9	.2	10	20.8	
							46.50	.3	6	16.3							20.0
							44.75	1.5	6	17.0							
							45.40	.6	6	16.7							
							45.60	.6	6	16.7	16.8						
13,000	48.3	.7	7	15.9		13,000	50.90	2.4	7	15.1		13,000	26.2	.2	11	18.7	
	48.5	.5	7	15.9	15.9		45.50	1.3	7	16.9			22.9	.1	11	21.4	20.0
							47.45	.7	7	16.2							
							45.45	1.5	7	16.9							
							53.80	.8	6	16.7							
							54.20	1.8	6	16.6	16.4						
15,000	58.8	.3	7	15.1		15,000	56.80	2.8	7	15.6		15,000	28.5	.2	12	18.2	
	58.4	.6	7	15.2	15.2		56.35	3.7	7	15.8			28.6	.1	12	18.0	18.1
							53.25	1.3	7	16.7							
							51.90	.3	7	17.1							
							52.00	1.0	7	17.0							
							52.60	.6	7	16.9	16.5						

JACK NUMBER 6.

Cylinder Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	33.2	.3	3	20.0	....	3,000	21.6	.4	3	30.7	....
5,000	52.1	1.4	3	21.2	....	5,000	40.5	1.5	3	27.2	....
7,000	40.2	.3	6	19.2	....	7,000	31.5	1.0	6	24.6	....
9,000	50.6	2.1	6	19.6	....	9,000	41.4	.6	6	24.0	....
11,000	60.5	1.0	6	20.2	....	11,000	49.2	2.2	6	24.7	....
13,000	59.1	.6	7	20.8	....	13,000	60.9	.7	6	23.6	...
15,000	59.5	1.0	8	20.9	....	15,000	55.1	3.1	8	22.6	....
.....	....	....	....	....	....	17,000	61.1	3.1	8	23.0	....

JACK NUMBER 7.

CYLINDER OIL.

Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	21.90	.9	2.75	16.5	....	7,000	24.20	.8	6	16.0	....
....	19.95	1.0	2.75	18.1	....	....	19.75	.6	6	19.6	....
....	20.95	1.5	2.75	17.3	....	....	23.35	4.8	6	16 6	....
....	18.70	1.5	2.75	19.3	....	....	19.70	.8	6	19.5	....
....	21.60	2 4	2.75	16 7	....	....	57 20	1.2	2 75	14.8	....
....	20.40	.6	2.75	17 7	....	....	47.80	1.2	2.75	17.7	....
....	21.50	1 5	2 75	16 8	....	....	56.35	2.1	2.75	15.0	....
....	21.00	2.0	2.75	17 2	....	....	53 85	1.2	2.75	16.7	....
....	22.80	1.2	2.75	15 9	....	....	58.40	2.4	2.75	14.5	....
....	22.40	1 6	2.75	16 1	....	....	48.00	1.0	2.75	17.6	....
....	21.10	.9	2.75	17.1	....	....	48.40	.6	2.75	17.4	....
....	26.65	2.7	2.75	13.6	....	....	25.10	2 1	6	15.4	....
....	22.05	2 0	2.75	16.4	....	....	22.55	1.5	6	16.7	....
....	21.50	.5	2.75	16 8	....	....	49.00	1.0	2.75	17.2	....
....	21.00	1.0	2.75	17.2	....	....	55.20	2.8	2.75	15 3	....
....	24.35	1.7	2.75	14.8	....	....	54.30	5.0	2.75	15.5	....
....	24.55	1.5	2.75	14.7	....	....	53.10	2.9	2.75	15.9	....
....	21.30	1.0	2.75	17.0	....	....	21.80	.8	6	17.8	....
....	20.60	.6	2.75	17.5	16.7	....	21.20	.3	6	18.2	16.7
5,000	39.05	1.0	2.75	15.4	....	9,000	31.10	1.0	6	16.0	....
....	35.00	1.5	2.75	17.2	....	....	28 35	.6	6	17.5	....
....	35.30	3 1	2 75	17.1	....	....	29.00	1.2	6	17.2	....
....	36.05	4 0	2.75	16 7	....	....	27.05	.3	6	18.4	....
....	41.00	2.0	2.75	14.7	....	....	32 80	1.2	6	15.2	....
....	34.80	2.8	2.75	17.3	....	....	29.40	1.6	6	16.9	....
....	40.70	4.2	2.75	14.8	....	....	31.05	3.0	6	14.9	....
....	39.35	1.8	2.75	15.3	....	....	28.70	2.3	6	17.3	....
....	41.60	1.4	2 75	14.5	....	....	34.80	1.8	6	14.3	....
....	35.10	.6	2.75	17.2	....	....	29.60	.6	6	16.8	....
....	34 30	.7	2.75	17.6	....	....	29.20	.7	6	17.0	....
....	43.60	3.6	2.75	13.8	....	....	31.65	2 4	6	15.7	....
....	36.60	1.6	2.75	16 5	....	....	29 35	1.7	6	16.9	....
....	35.20	.8	2.75	17.1	....	....	26 60	2 4	6	18 7	....
....	33.60	4.4	2 75	17.9	....	....	32.20	1.8	6	15.4	....
....	38.40	2.4	2 75	15.7	....	....	32.96	1.1	6	15.1	....
....	36.35	2.4	2.75	16.6	....	....	32.50	1.5	6	15.3	....
....	36.50	1.5	2.75	16.5	....	....	31.60	.6	6	15.7	....
....	32.50	.5	2.75	18 6	16.4	....	28 40	.6	6	17.5	16.4

JACK NUMBER 7.— *Continued.*

CYLINDER OIL.

Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
11,000	39.50	1.5	6	15 4	....	15,000	53 60	1.4	6	15.5	....
....	33.90	.4	6	17.9	....	....	51.40	1.4	6	16 1	....
....	35.40	1.9	6	17.2	....	....	50.50	.8	6	16.4	....
....	34.15	.8	6	17.8	....	....	51.55	2.5	6	16.1	....
....	39.60	2.4	6	15.4	....	....	54.00	2.0	6	15.4	....
....	36.40	2.0	6	16 7	....	....	53.40	1.6	6	15.5	....
....	40.75	3.2	6	14.9	....	....	54.95	3.4	6	15.1	....
....	36.85	2.8	6	16.5	....	....	48.95	3.0	6	17.0	....
....	43.50	1.5	6	14.0	....	....	59.50	.5	6	13.9	....
....	38.40	1.0	6	15 8	....	....	59.00	1.0	6	14.0	....
....	38 90	.5	6	15 6	....	....	59.50	.5	6	13.9	....
....	37.10	4.3	6	16.4	....	....	56.10	1.4	7	12.7	....
....	35.00	2.5	6	17.4	....	....	56 25	3.0	7	12.6	....
....	36.20	.8	6	16 8	....	....	54.40	3.6	7	13.0	....
....	35.40	1 6	6	17.2	....	....	52.00	2.0	7	13.7	....
....	40.15	1.1	6	15 2	....	....	55.60	1.4	7	12 8	....
....	39.55	1.5	6	15.4	....	....	49.05	1.0	7	14.5	....
....	38.20	.8	6	15.9	....	....	54.60	1.4	7	13.0	....
....	33.30	.7	6	18.2	16.3	....	52.70	1.3	7	13 5	14.5
13,000	49.80	1.8	6	14.4	....	....	....	....	....	....	....
....	43.30	.8	6	16 6	....	....	....	....	....	....	....
....	45.50	1.7	6	15.8	....	....	....	....	....	....	....
....	44.20	2.2	6	16 3	....	....	....	....	....	....	....
....	44.20	1.8	6	16 3	....	....	....	....	....	....	....
....	43.20	.8	6	16.6	....	....	....	....	....	....	....
....	52.45	2.4	6	13.7	....	....	....	....	....	....	....
....	45.25	3.0	6	15.9	....	....	....	....	....	....	....
....	52.20	1.2	6	13.8	....	....	....	....	....	....	....
....	48 60	1.4	6	14.8	....	....	....	....	....	....	....
....	49.50	1.5	6	14.5	....	....	....	....	....	....	....
....	48 30	3.2	6	14 8	....	....	....	....	....	....	....
....	43 80	1.2	6	16 4	....	....	....	....	....	....	....
....	50.00	2 0	6	14.4	....	....	....	....	....	....	....
....	48.40	1 6	6	14.8	....	....	....	....	....	....	....
....	52.20	3.2	6	13.8	....	....	....	....	....	....	....
....	47.30	2.3	6	15 2	....	....	....	....	....	....	....
....	41.10	1.4	7	15.0	....	....	....	....	....	....	....
....	38.40	.6	7	16.0	15.3	....	....	....	....	....	....

JACK NUMBER 7. — *Concluded.*

Light Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	27.32	2.3	2.75	13.2		3,000	22.5	.8	2.75	16.1	....
	24.90	1.1	2.75	14.5							
	22.50	1.5	2.75	16.1	14.6						
5,000	47.40	2.4	2.75	12.7		5,000	35.9	2.7	2.75	16 8	....
	43.75	.8	2.75	13.8							
	33.94	1.0	2 75	17.8							
	34.17	1.6	2.75	17.6	15.5						
7,000	30.48	.8	6	12 7		7,000	55.7	4.8	2.75	15.2	....
	54.70	.7	2.75	15.4							
	49.00	1.0	2.75	17.2	15.1						
9,000	36.79	2.0	6	13.5		9,000	36.9	3.2	6.0	13.5	....
	32.90	1.1	6	15.1							
	31.17	1.9	6	16.0							
	31.14	.8	6	16.0	15.1						
11,000	44.27	2 5	6	13.7		11,000	42.9	1.6	6.0	14.2	....
	41.40	.6	6	14.7							
	37.10	.9	6	16.4							
	36.57	.4	6	16.6	15.3						
13,000	51.39	1.0	6	14.0		13,000	51.6	1.5	6.0	13.9	....
	50.60	.6	6	14.2							
	44.64	.6	6	16.1							
	43.37	.7	6	16.6	15.2						
15,000	57.33	1.6	6	14.5		15,000	47.3	.8	6.0	15.0	....
	48.50	1.5	7	14.7							
	51.14	.8	6	16.2							
	49.83	1.2	6	16.6	15.5						

JACK NUMBER 8.

Light Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	12.39	1.6	3	26 8		3,000	17.5	.2	3	18.9	....
	13.07	1.0	3	25.4	26.1						
5,000	22.70	1.8	3	24.3		5,000	25.5	.0	3	21.6	....
	21.40	1.0	3	25.8	25.0						
7,000	31.40	1.0	3	24.6		7,000	43.2	.3	3	17.9	....
	32.93	3.0	3	23.5	24.0						
9,000	24.55	1.5	6	20 3		9,000	47.8	1.3	3	20.8	....
	25.95	.4	6	19 2	19.8						
11,000	28.17	1 8	6	21 6		11,000	26.1	1.4	6	23.3	....
	28.33	1.7	6	21 5	21.6						
13,000	29.90	.5	6	24.0		13,000	29.1	.4	6	24.7	....
	30.90	1.1	6	23.3	23.8						
15,000	37.45	2.5	6	22.1		15,000	35.3	1.2	6	23.5	....
	35.12	2.4	6	23.6	22.9						

JACK NUMBER 9.

Light Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	13 9	1.0	3	23.9		3,000	12.7	.5	3	26.1	....
	17.0	1 0	3	19.6							
	16 0	1 0	3	20.7	21.4						
5,000	21.0	.5	3	25.6		5,000	24.0	1.0	3	23.1	....
	23.7	1.0	3	23.4							
	22.5	.5	3	24.6	24.4						
7,000	30.5	.5	3	25.4		7,000	40.5	2.0	3	19.1	....
	14.7	1.3	6	26.3							
	17.3	1.2	6	22.4	24.7						
9,000	42.4	1.4	3	23.5		9,000	47.1	2.4	3	21.1	....
	22 0	1.0	6	22.6							
	22.5	1.0	6	22.1	22.7						
11,000	23.8	.3	6	25.5		11,000	31.6	3.0	6	19.3	....
	24.6	.9	6	24.7							
	24.7	.7	6	24.6	24.9						
13,000	28.4	.4	6	25.3		13,000	38.5	3.0	6	18.7	....
	36.2	1 0	6	19.8							
	34.6	1.6	6	20.8	21.9						
15,000	46.0	2.0	6	18.0		15,000	42.1	5.0	6	19.7	....
	38.8	1.2	6	21.4							
	36 4	3.0	6	22 8	20 7						

JACK NUMBER 11.

Light Oil.						Tallow and Graphite.					
Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.	Loads.	Av. pull on lever. (Pounds.)	Maximum variation from average.	Length of lever. (Feet.)	Efficiency.	Average efficiency.
3,000	13.71	.4	3	24.2		3,000	21.6	1.6	3	15.4	....
	11.54	1.0	3	28.7	26.5						
5,000	23.11	2.0	3	23.9		5,000	30.1	1.4	3	18.4	....
	21.33	.3	3	25.9	24.9						
7,000	26.79	1.2	3	28.9		7,000	42.6	.9	3	18.2	....
	30.10	2.5	3	25.7	27.3						
9,000	17.40	1.2	6	28.6		9,000	47.5	4.	3	21.0	....
	18.00	1.0	6	27.6	28.1						
11,000	20.92	.9	6	29.0		11,000	28.8	.7	6	21.1	....
	19.90	1.4	6	30.6	29.8						
13,000	27.40	1.9	6	26.2		13,000	31.2	1.3	6	23.0	....
	27.80	.3	6	25.8	26.0						
15,000	29.00	1.0	6	28.6		15,000	36.1	1.4	6	23.0	....
	27.65	.7	6	30.0	29.3						

SUMMARY OF TESTS.

	Jack No. 1.			Jack No. 2.			Jack No. 3.		
Loads.	Light oil.	Cylinder oil.	Beef tallow and graphite.	Light oil.	Cylinder oil.	Beef tallow and graphite.	Light oil.	Cylinder oil.	Beef tallow and graphite.
3,000	16.9	15.1	16.4	12.2	12.3	13.5	9.5	10.8	10.6
5,000	16.9	15.4	17.3	12.6	12.3	12.6	9.9	10.5	10.3
7,000	17.0	16.2	17.6	12.5	12.5	13.6	9.9	11.6	9.8
9,000	16.3	16.5	18.1	12.2	12.4	13.8	9.5	11.4	10.0
11,000	15.2	16.5	18.4	12.3	12.8	13.4	10.0	11.7	10.1
13,000	16.4	16.7	18.6	12.2	12.8	13.7	....	11.5	....
15,000	15.7	16.6	18.4	12.3	12.9	14.3	....	....	....

	Jack No. 4.			Jack No. 5.			Jack No. 6.	
Loads.	Light oil.	Cylinder oil.	Beef tallow and graphite.	Light oil.	Cylinder oil.	Beef tallow and graphite.	Cylinder oil.	Beef tallow and graphite.
3,000	12.4	13.3	14.8	15.8	15.6	19.7	20.0	30.7
5,000	12.5	13.4	13.1	16.0	16.6	20.0	21.2	27.2
7,000	13.2	13.6	13.0	16.0	16.7	19.6	19.2	24.6
9,000	13.5	13.7	13.9	15.0	16.1	20.6	19.6	24.0
11,000	13.2	14.0	14.0	15.4	16.8	20.0	20.2	24.7
13,000	13.4	14.5	14.2	15.9	16.4	20.0	20.8	23.6
15,000	13.1	14.7	13.7	15.2	16.5	18.1	20.9	22.6

SUMMARY OF TESTS — *Concluded.*

	Jack No. 7.			Jack No. 8.		Jack No. 9.		Jack No. 11.	
Loads.	Light oil.	Cylinder oil.	Beef tallow and graphite.	Light oil.	Beef tallow and graphite.	Light oil.	Beef tallow and graphite.	Light oil.	Beef tallow and graphite.
3,000	14.6	16.7	16.1	26.1	18.9	21.4	26.1	26.5	15.4
5,000	15.5	16.4	16.8	25.0	21.6	24.4	23.1	24.9	18.4
7,000	15.1	16.7	15.2	24.0	17.9	24.7	19.1	27.3	18.2
9,000	15.1	16.4	13.5	19.8	20.8	22.7	21.1	28.1	21.0
11,000	15.3	16.3	14.2	21.6	23.3	24.9	19.3	29.8	21.1
13,000	15.2	15.3	13.9	23.8	24.7	21.9	18.7	26.0	23.0
15,000	15.5	14.5	15.0	22.9	23.5	20.7	19.7	29.3	23.0

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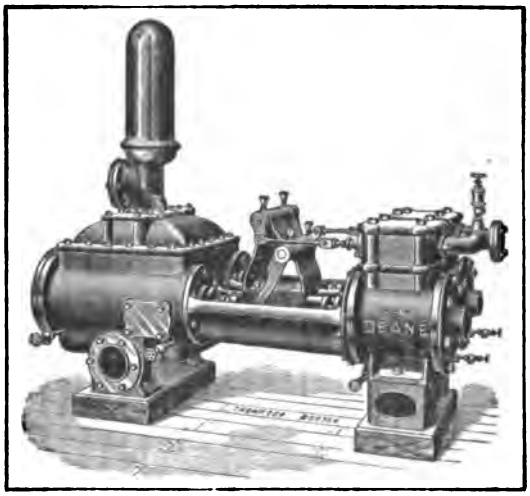

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